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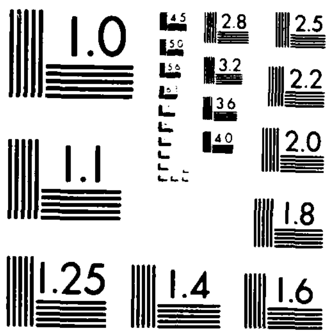

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ADVANCED AVIONICS SYSTEM ANALYSIS

Modular Avionics Cost Benefit Study Formulation

The Analytic Sciences Corporation
3040 Presidential Drive
Fairborn OH 45324

February 1987

Final Report for Period September 1983 - January 1986

Approved for public release; distribution is unlimited

AVIONICS LABORATORY
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This technical report has been reviewed and is approved for publication.

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This is a technical baseline for a cost benefit analysis of optional features of an advanced modular avionics architecture for the mid-1990s. It provides an outline of a projected life cycle cost for alternate configurations for future avionics (including cost for implementation and supportability).

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FOREWORD

This Technical Report has been written to document the initial formulation of a technical baseline for a cost benefit analysis of optional features of an advanced modular avionics architecture for the mid-1990s. The advantages offered by such features as line replaceable modules using VHSIC and software for dynamic reconfiguration have been assumed but little attention has been paid to interactions among the factors or projected costs of incorporating them into a system. Selection of features from a set of alternatives must be made on the basis of total life cycle cost impact and the benefit to the overall weapon system performance. Many of the factors set out to improve mission completion reliability. Not all of them are equally efficient in improving performance for the cost expended. This study includes discussion of the factors and establishes the baseline for a life cycle cost analysis of alternatives. Estimates of life cycle cost impacts coupled with the relative benefits to be gained will allow the decision maker to select the most effective strategy for implementing modular avionics.

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1. INTRODUCTION

The objective of this study is to set the baseline for a cost/benefit analysis of alternatives for a modular avionics architecture for the mid-1990s. Figure 1-1 shows each phase of the overall cost/benefit analysis. The objective of each of the alternatives is to improve the mission performance or reduce the life cycle cost of the avionics suite. The alternatives have been selected from the many studies and reports included in the bibliography that have addressed the implementation of modular avionics to improve avionics performance and reduce cost. Performance, as used here, is the ability to perform the mission. Both performance and cost are influenced by reliability. Hardware reliability influences operation and support costs as well as mission reliability. If hardware reliability cannot be improved, the objectives are to improve mission reliability by replicating the hardware paths (redundancy) and to reduce the costs of detecting, isolating, and repairing hardware faults that do occur. The alternatives discussed in this study address one or both of the objectives. Their efficiency in meeting both objectives is the fundamental criterion the alternatives are measured against.

It is necessary to define an operating scenario in order to evaluate life cycle costs using simulation models. This scenario includes the weapon system and the suite of avionics on board. A generic fighter aircraft similar to the F-15 and the F-16 was assumed for the baseline platform. The avionics suite includes equipment now under development in ASD

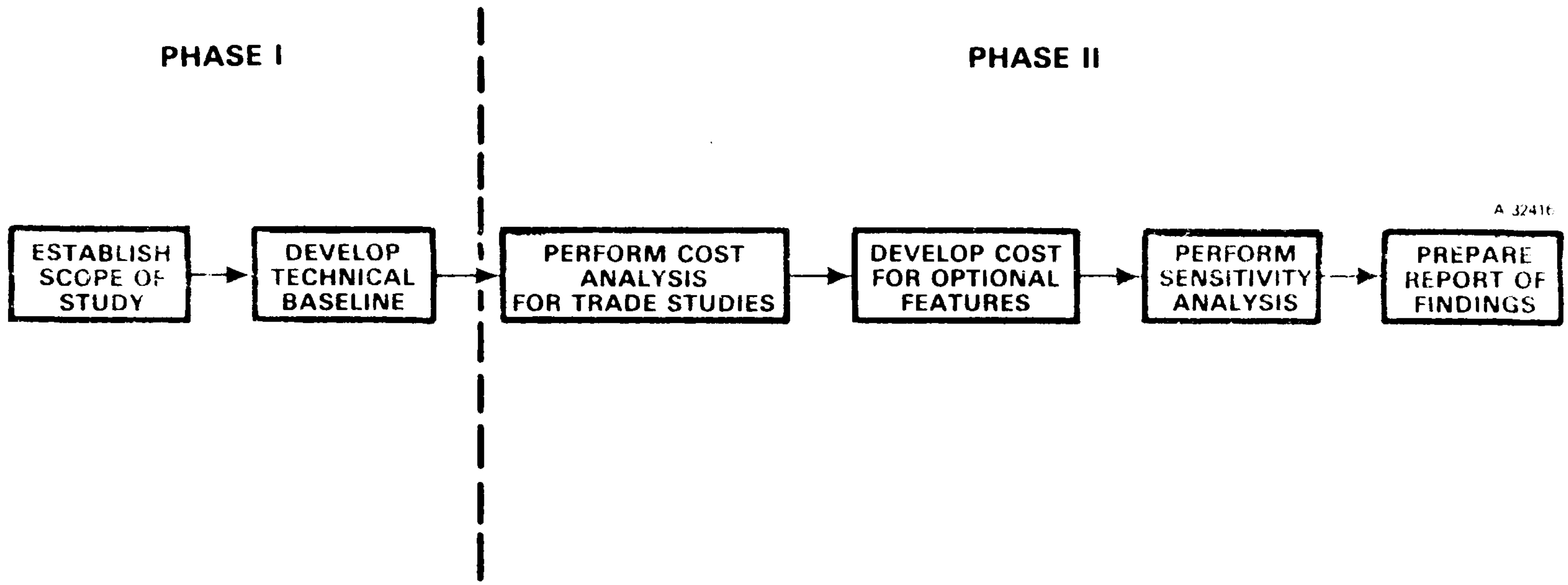

Figure 1-1 Standard Modular Architecture Cost/Benefit Study

and the laboratories in such programs as Integrated Communications Navigation Identification Avionics (ICNIA), Ultra Reliable Radar (URR), Common Signal Processor (CSP), and the VHSIC 1750A Data Processor. Module types and sizes are typical of systems currently being developed. A central element of the decision analysis is the comparison of line replaceable units (LRUs), which include subassemblies removable at intermediate maintenance levels, to line replaceable modules (LRMs) which are removed at the flight line and repaired at the depot level. The same VHSIC technology base has been assumed for either LRUs or LRMs to avoid confusing the technology influence with partitioning and packaging effects.

Each of the factors to be considered in establishing a preferred modular architecture is described and decision criteria to select alternatives are developed. It is expected that the baseline established in this study will be used in a subsequent analysis phase to develop life cycle cost estimates for the alternatives.

2. BACKGROUND

Avionics subsystems in today's weapon systems have become increasingly complex and sophisticated in order to meet ever increasing requirements. As the role of avionics in critical areas of flight control, engine control, and mission performance increases so does the requirement for avionics reliability. The consequence of electronic failure in flight and engine control applications may be loss of the aircraft. The digital flight control processor in the F-15E, for example, is triplex redundant. The flight control electronics for the most recent F-16 is quad redundant. Today's fighter aircraft avionics suites average in the range of 15 to 35 flight hours between critical failures, according to AFM 66-1 data with an average time to repair a failure of over two hours. Today approximately one quarter of the total aircraft maintenance man-hours per flying hour are spent on avionics problems. Both the F-15 and the F-16 aircraft rely upon an avionics intermediate shop (AIS) at the intermediate maintenance level. In future systems, the AIS may be too vulnerable and inflexible for the predicted support environment.

Air battle planners see the trend for an increasingly important role for avionics continuing into the mid-1990s, but in a support environment that is expected to change. Planners anticipate the use of a few main support bases from which aircraft will deploy to operational bases, with subsequent deployment from the operational bases to dispersed operating locations. Off-equipment maintenance requirements must be minimized in this mobile, flexible support scenario. Unfortunately, an AIS is large and expensive, and over four C-141s are required to deploy the AIS for one F-16 wing and the F-15 AIS is even larger. Since an AIS is large, expensive, and vulnerable, reliance on it must be reduced for future aircraft. Planners predict improvements in mean flying hours between critical failure in the hundreds of hours and avionics availabilities of 95 percent or better if future sortie requirements are to be met. The mean time to repair must be reduced from two hours to fractions of an hour if the projected surge rate of up to five sorties per day is to be achieved.

Modular avionics architectures have been offered as part of the solution to meet the needs for both high reliability and reduced reliance on flight line support equipment. Modular avionics architectures have included many different features designed to reduce life cycle cost, improve mission reliability, improve maintenance efficiency, or eliminate the AIS. Each of these factors must be evaluated individually to estimate their contribution to the goals of the overall avionics concept in comparison to their cost of implementation.

The use of line replaceable modules stems from Navy initiatives to simplify their support problems with shipboard electronics. Their Standard Electronic Modules (SEMs) were designed to be low part count building blocks from which most electronic functions could be built. When the small building block failed, it was thrown away. The Navy SEM concept offered standardized building blocks which could reduce the spares complement needed to maintain the shipboard electronics. This concept had two principal shortcomings that did not make it attractive for airborne use. Because the modules were small, packaging density and circuit board efficiencies could not be achieved, and the weight and volume requirements were excessive. Since the module circuitry was standardized, technology advances could not be expeditiously implemented and design stagnation resulted. The Aeronautical Systems Division, Directorate of Avionics Standardization and Systems Architecture prepared a module development and implementation plan in the mid 1970s that set some ground rules for a USAF module program that stressed the need to allow for technological advance and the need for efficient functional partitioning. The ground rules are still appropriate for application today. Advances in semiconductor integrated circuit technology that have resulted in Very High Speed Integrated Circuits (VHSIC) may make it possible to efficiently partition functional elements at the module level. Although much has been written about the benefits of VHSIC LRMs, few cost/benefit analyses have been performed because of the uncertainty in predicting both costs and reliability of the technology. Now that design efforts are underway using Phase I VHSIC technology, some cost and reliability projections are available. Advances in technology may be accommodated if standardization is limited to form, fit, function and interface. The circuitry and techniques used to implement the function are not controlled.

Program Management Directive (PMD) 5059(1)63253F/3003, dated 25 January 1985, directed the development and production of a Standard Modular Avionics System Architecture (SMASA) for incorporation in Air Force weapon systems. Key factors in this architecture included the use of form, fit, function, and interface standardization of line replaceable modules, on-board test capability, time stress measurement devices (TSMDs), the use of the Integrated Maintenance Information System (IMIS), and management software to allow dynamic reconfiguration of module tasks in flight. Each of these factors is intended to improve mission reliability and r duce life cycle cost.

An evaluation of their interactions and cost is necessary to allow a decision maker to choose the appropriate mix of alternatives which can achieve the necessary objectives of reduced maintenance requirements on the flight line, greater availability, and better mission reliability, while reducing the life cycle cost of the fielded avionics suite. Hardware reliability is the most important factor involved in achieving the objectives established for avionics in the mid-1990s. If the reliability is sufficiently high, the maintenance needs and consequently the operation and support costs are reduced. Increased reliability must be achieved during the early design phase. A thorough understanding of the mission and maintenance environment is necessary and adequate funding of the design for the environment must be included in the program planning. When the best possible hardware reliability has been achieved, the options open to the decision maker include the minimization of the maintenance burden through incorporation of a mix of the factors discussed in this cost/benefit study formulation.

3. STUDY DESCRIPTION

The structure of an avionics suite in a weapons system is a result of many design decisions throughout the program formulation and development. Selection of the optimum technical concept for modular avionics may not be possible because of the uncertainties in factor interactions and the changing needs of the decision makers. The selection of a preferred concept based upon the best information available should be the goal. The results of the cost/benefit study should aid the decision maker in selecting the preferred concept for modular avionics.

A systematic approach for identifying and selecting alternatives must be used in formulating a cost/benefit study. The modular avionics architecture in this study is in an early conceptual phase, so many factors which influence the concept selection and the system life cycle cost are subject to change. Table 3-1 includes a list of factors discussed in the background studies and identified in the SMASA PMD of January 1985. This list is by no means an exhaustive list of factors involved in an overall program, but it represents salient features and alternatives that must be considered in the formulation of the cost/benefit study. Table 3-1 organizes the factors into five categories representing major program life cycle cost elements. Each of the factors is discussed in the following sections.

TABLE 3-1

FACTORS INFLUENCING A MODULAR AVIONICS ARCHITECTURE

Program Management
Utilization of a Central Certification Facility
Configuration Management Library
Acquisition and Development
Product Performance Agreements
Competition
Design
Functional Partitioning to LRM or LRU
Standardization
Time Stress Measurement Device Incorporation
Inclusion of a Dedicated Maintenance Processor
Testability/Off-Equipment/On-Equipment Test Alternatives
Reconfiguration/Software Development Needs
Operation
Deployment Requirements
Base Locations
Weapon System Quantities
Support
Use of Modular Automatic Test Equipment
Use of Integrated Maintenance Information System
Location of Depot Repair Facility
Selection of Maintenance Strategy
Scheduled Vs. Unscheduled Maintenance

3.1 PROGRAM MANAGEMENT

3.1.1 Certification Facility

A central certification facility is beneficial in maintaining control of unit configuration and initial design quality when a number of manufacturers are required to design to a standard. The facility may be helpful in maintaining an efficient quality assurance program which leads to high module reliability. The need for the facility is independent of the decision to partition into LRMs or LRUs. The decision to utilize a certification facility, Government-manned or contractor manned, will depend upon the estimated cost in relation to the improved reliability, the gain of central data control, and the projected decrease in life cycle cost. The need to centralize control increases as the degree of standardization increases and the ability to efficiently and unambiguously test for compliance with the standard decreases. The costs for introducing a certification facility may be estimated separately for inclusion in a final decision matrix.

3.1.2 Configuration Management Library

Maintaining close control of unit configuration may be necessary where standardized units are used in many applications. A central configuration management facility could provide a useful service in maintaining a library of standard unit technical descriptions available for use by system designers. The library items maintained could include interface descriptions, qualification and performance data, and electrical schematics. The data could be maintained in a selected Computer Aided Design (CAD) format to serve the user needs most efficiently by allowing remote electronic access to the information. The library items would not necessarily be required for use on all programs but their use may be encouraged by contract. The configuration management facility could be maintained by the government, or it could be maintained under contract to the government organization responsible for modular avionics. The alternative would be to rely upon existing professional societies or industry associations to voluntarily monitor and disseminate standard technical descriptions. The cost of these optional strategies can be estimated and included in the overall cost summary.

3.2 ACQUISITION AND DEVELOPMENT

3.2.1 Product Performance Agreements

Product performance agreements (PPAs) including warranties, guarantees, and other contractual devices are required by federal law for most major weapon systems. The PPA is used to provide incentive to the contractor to meet or exceed performance requirements. The PPA should be tailored to the needs of the specific program. For example, if the risk associated with meeting performance is high, the PPA can be structured to offer incentives to meet the performance. Conversely, if the hardware design is an off-the-shelf standard unit, a complex reliability improvement warranty may not be cost effective. The cost of the PPA must be considered in the life cycle cost estimate.

The Product Performance Agreement Center's (PPAC's) automated Decision Support System (DSS) was used to determine potential warranty approaches for this program. Warranty selections were made based on program objectives and equipment characteristics as they are known at this time. The list of potential warranties included:

- Reliability Improvement Warranty (RIW)
- Mean Time Between Failure Verification Test (MTBF-VT)
- Logistics Support Cost Guarantee (LSCG)
- Incentive Award
- Reliability Guarantee
- Availability Guarantee
- Component Reliability Guarantee
- Interim Contractor Support
- Chronic LRU Guarantee
- Repair/Exchange Agreement
- Correction of Deficiencies
- Commercial Service Life.

3.2.2 Competition

A potential factor in reducing acquisition cost and in maintaining quality in subsequent avionics procurements is competition. Competing companies will hold their proposed costs down and will maintain a cost effective production facility when follow-on buys are expected to be competed. Product quality will receive greater emphasis if the result of poor quality is loss of follow-on business. To have competition, multiple sources of supply must be available and willing to bid on the initial contract and on subsequent contracts. Standardization of requirements can increase the order size and, consequently, attract multiple potential sources. Form, fit, and function standardization allows alternative design solutions to be proposed which can foster competition while reducing the possibility of technological stagnation. Competition may be fostered by awarding multiple contracts for hardware development and for subsequent production. Leader-follower contracting approaches can be used to retain competition in subsequent buys of the avionics assemblies.

3.3 DESIGN

3.3.1 Partitioning

Partitioning in a general context, is the allocation of circuit functions to separately identifiable assemblies or software modules. In general, the life cycle costs are not expected to be sensitive to moderate changes in module or printed wiring assembly size, unless those changes impact the way the units are supported. For the purposes of the study we are most interested in the partitioning of the functions to line replaceable units containing separate shop replaceable units or in the partitioning of functions to line replaceable modules that are not expected to undergo further disassembly at intermediate level. The differences between LRUs and LRMs should be apparent in the life cycle cost comparisons.

Included in the design category are a number of factors that represent critical decision points in selecting a preferred avionics concept. The primary decision centers on selection of an LRM or an LRU for the basic hardware building block of the avionics architecture. If the acquisition cost of the line replaceable element can be kept low and the reliability can be made to be high, significant reductions in operation and support costs are possible as suggested by Dougherty in Reference 1. His proposed criteria for the elimination of the intermediate maintenance level is shown in Fig. 3.3-1. If the acquisition cost per failure free operating hour lies to the

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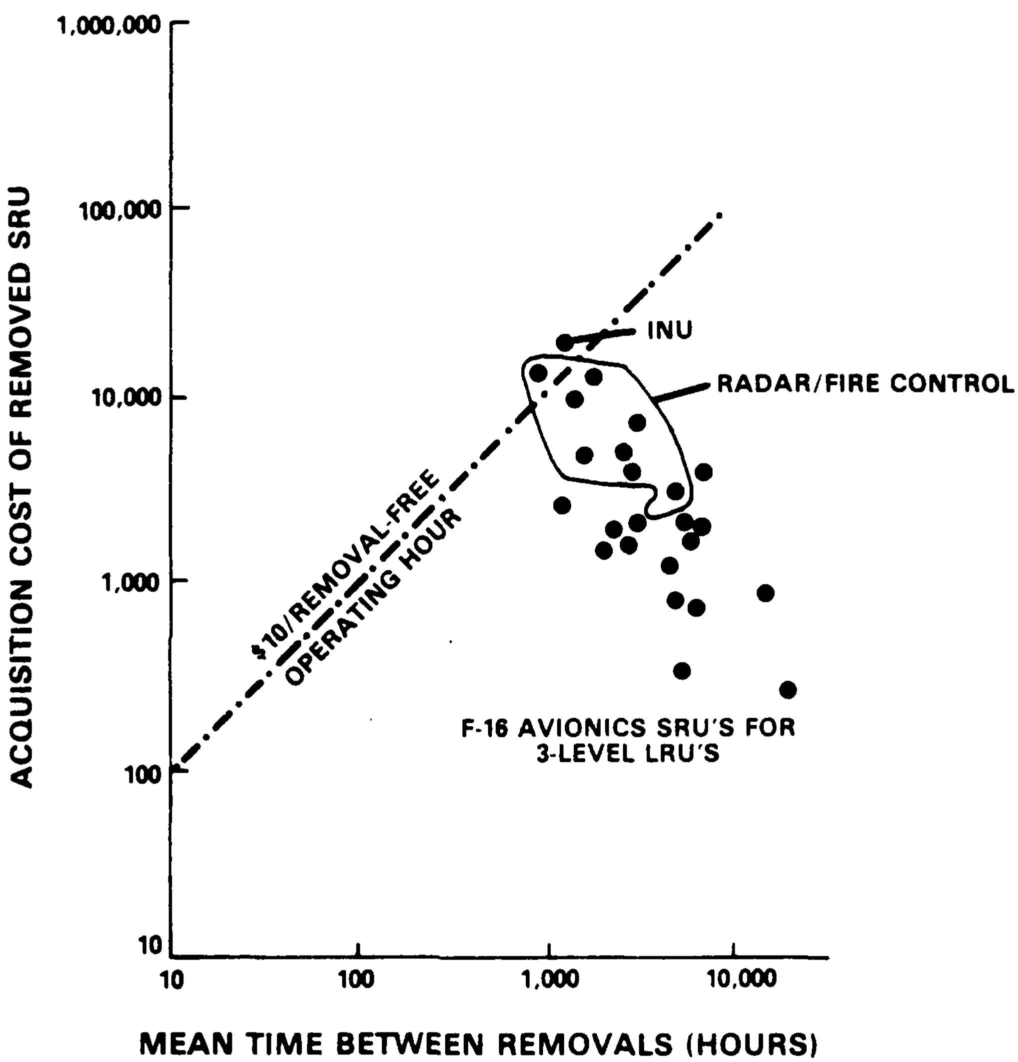

Figure 3.3-1 Evaluation Criteria for Determining Maintenance Level

right of the trend line, use of a two-level maintenance strategy is cost effective. To the left of the trend line, a three-level maintenance strategy should be employed.

Reductions in component count by partitioning to smaller line replaceable elements are expected to increase availability and reduce costs. Further benefits are assumed as the design is partitioned to smaller functional elements which lend themselves to standardization. The costs for both LRU and LRM alternatives should be fully developed in the cost/benefit study.

3.3.2 Standardization

The degree of standardization is a significant factor in life cycle cost determination. The interoperability benefits of interface standardization using the MIL-STD-1553 multiplex data bus are recognized by industry and have been documented in the technical literature. Form, fit, and function standardization at the LRU level has been used with success in avionics applications such as the standard inertial navigation system and the standard central air data computer. Although standardization down to the circuit design level would offer some reductions in support costs, the price paid in technology stagnation and limiting competition may be large. The optional use of elements common within a weapon system may reduce the operation and support cost through reduction in the spares types needed, without the interoperability concerns which accompany the use of standardized hardware. It may be possible to realize some design cost savings by using common modular elements, but the savings may be offset by the burden of constraining the designer to conform to the limitations of available common elements. The cost of common modules will be developed for the LRM alternative only, since an analogous common LRU does not appear to be practical.

3.3.3 Testability

Testability is an important element in the definition of a modular avionics concept. The percentage of off-equipment to on-equipment testing should lean heavily toward on-board test (OBT) in order to reduce the requirement for external support equipment. OBT should reduce the overall life cycle cost while improving operational effectiveness. OBT can provide an indication of performance to the aircrew as in the case of an initiated self-test during preflight. OBT can also provide fault prediction, detection and isolation for maintenance. The potential for prediction in avionics has not yet been fully explored. Detection and isolation must be taken to the line replaceable element in order for OBT to be effective. The importance of OBT detection and isolation functions increase as fault tolerance through dynamic reconfiguration of hardware task assignments is introduced. Intermittent or non-functioning OBT will adversely affect reconfiguration capability and reduce mission reliability. OBT can be expected to utilize 25 percent or more of module surface area even with the on-chip test capability of VHSIC fully utilized. The selected testability strategy will have a significant effect on life cycle cost, both in terms of initial development and operations and support. The strategy may include a dedicated maintenance processor to track information on intermittent failures, the redundancy levels used, history of reconfiguration, and environmental exposure history.

3.3.4 Time Stress Measurement Device (TSMD)

The TSMD is a stress and time sensor integral to the electronic equipment. The purpose of the TSMD is to sense the environment for recording and later use. Usage can vary from test instrumentation for initial qualification to continuous real time monitoring of the environment. Initial development work by Battelle Columbus Laboratories and Minneapolis Honeywell has demonstrated the feasibility of the concept. Work still remains to reduce the size of the TSMD and to develop an overall OBT strategy which includes the TSMD. It is now possible to consider incorporating a TSMD in each line replaceable unit as the required area is reduced using VHSIC technology. Storage of data is still expected to pose a problem. Since the memory available to dedicate to this storage task is expected to be limited, only selected data should be recorded such as parameter excursions above a threshold. Temperature, temperature rate, vibration, and power are expected to influence the electronics and consequently should receive recording priority. For vibration, the spectrum must be divided into segments. Excursions above preset thresholds in each of the segments would be recorded. The TSMD system includes not only the sensor embedded within the equipment, but also the data recording and data reduction equipment required.

3.3.5 Reconfiguration/Software Development Needs

The prototype architecture for the modular avionics cost benefit study is a PAVE PILLAR distributed, reconfigurable multiprocessor architecture. An architecture of this general form could be implemented using LRUs or LRMs. As noted previously, it is necessary to break an overall strategy into component parts and to make simplifying assumptions in order to evaluate alternative concepts for a multifaceted program such as this. One such component part is the real-time operating system software needed to tie the application dependent software modules together, and to further control the reconfiguration of the system upon failure of a host processor or interface. The assumption is made that an alternative approach would allow the application dependent software modules to operate autonomously in dedicated processors as in a conventional fighter weapon system of the mid-1980s. The difference in cost will be the development and maintenance cost of the management software. The potential benefit will be derived from the increase in mission reliability brought about through dynamic reconfigurability.

3.4 OPERATION

The operational factors influencing the selection of a modular avionics architecture include weapon system quantities, base locations, and deployment requirements.

It is assumed that many current weapon system characteristics are adequate to evaluate systems to be deployed in the mid 1990s. The operational factors are discussed in detail in the section on scenario development, so no additional discussion of this factor will be included here.

3.5 SUPPORT

3.5.1 Modular Automatic Test Equipment (MATE)

If external support equipment is required for off equipment maintenance, the option exists to use MATE. The alternative is to develop that equipment tailored to the needs of the modular avionics concept. Since use of MATE is not a central issue in the study being formulated, it will be evaluated separately so the costs may be included in an overall life cycle cost analysis. It is anticipated that with OBT, off-equipment maintenance needs will be minimized.

3.5.2 Integrated Maintenance Information System (IMIS)

Research has been sponsored by the Logistics and Human Factors Division of the Air Force Human Resources Laboratory to develop a means to integrate and deliver automated flightline maintenance information from various sources. IMIS makes use of a portable computer to display graphical technical data, to interrogate on-board systems, and to analyze in-flight failure information. The IMIS will provide intelligent diagnostic advice for maintenance personnel and IMIS should reduce the maintenance personnel needed to perform the wide range of maintenance required in the tactical environment. The need for IMIS is dependent upon the testability concept adopted. If the maintenance is simplified through use of on-board test, flight line maintenance information may not be required, but the fault information downloaded from the aircraft systems may be very useful in speeding turnaround of aircraft on the flight line.

3.5.3 Depot Repair Facility

A key consideration for selecting a depot repair facility is the use of a contract facility versus a Government facility. With the increase in reliability of hardware and sophistication of testing anticipated with VHSIC modular avionics, it is possible that contracting for depot repair may be a viable option. The repair facility could be made part of the certification facility. A second option is to contract for repairs by the vendor using a warranty agreement. Cost estimates for the contracted depot repair should be developed for evaluation of alternatives. This optional factor is independent of the central decisions associated with selection of LRMs versus LRUs so it may be evaluated separately and added to the results at the conclusions of the study.

3.5.4 Maintenance Strategy

Some factors regarding maintenance strategy have been previously discussed, but one additional factor associated with the study is the decision to use scheduled versus unscheduled maintenance. Unscheduled maintenance or maintenance on-demand has been the normal maintenance mode for avionics. As reliability of hardware elements is increased and the understanding of the mechanisms of failure improves, scheduled maintenance becomes possible. Maintenance on-schedule can reduce the AIS requirements and improve mission reliability. If the causes of hardware failure have been isolated, expected failure free time can be predicted, allowing for depot-only maintenance of line replaceable elements on a predetermined schedule. The cost and potential benefits for this factor may be developed separately for optional inclusion in a final strategy.

3.6 STUDY ORGANIZATION

The many factors influencing the selection of a preferred modular concept have been individually discussed. Each of the factors is intended to contribute to improved mission reliability and reduced life cycle cost. There is interaction among some of the factors while others are independent. Figure 3.6-1 shows the relationship among the primary or core factors through use of a decision tree.

In order to provide a logical basis for selection of a preferred concept, it is necessary to first establish the criteria upon which the selection is to be made. This establishment of decision criteria is discussed in the next chapter.

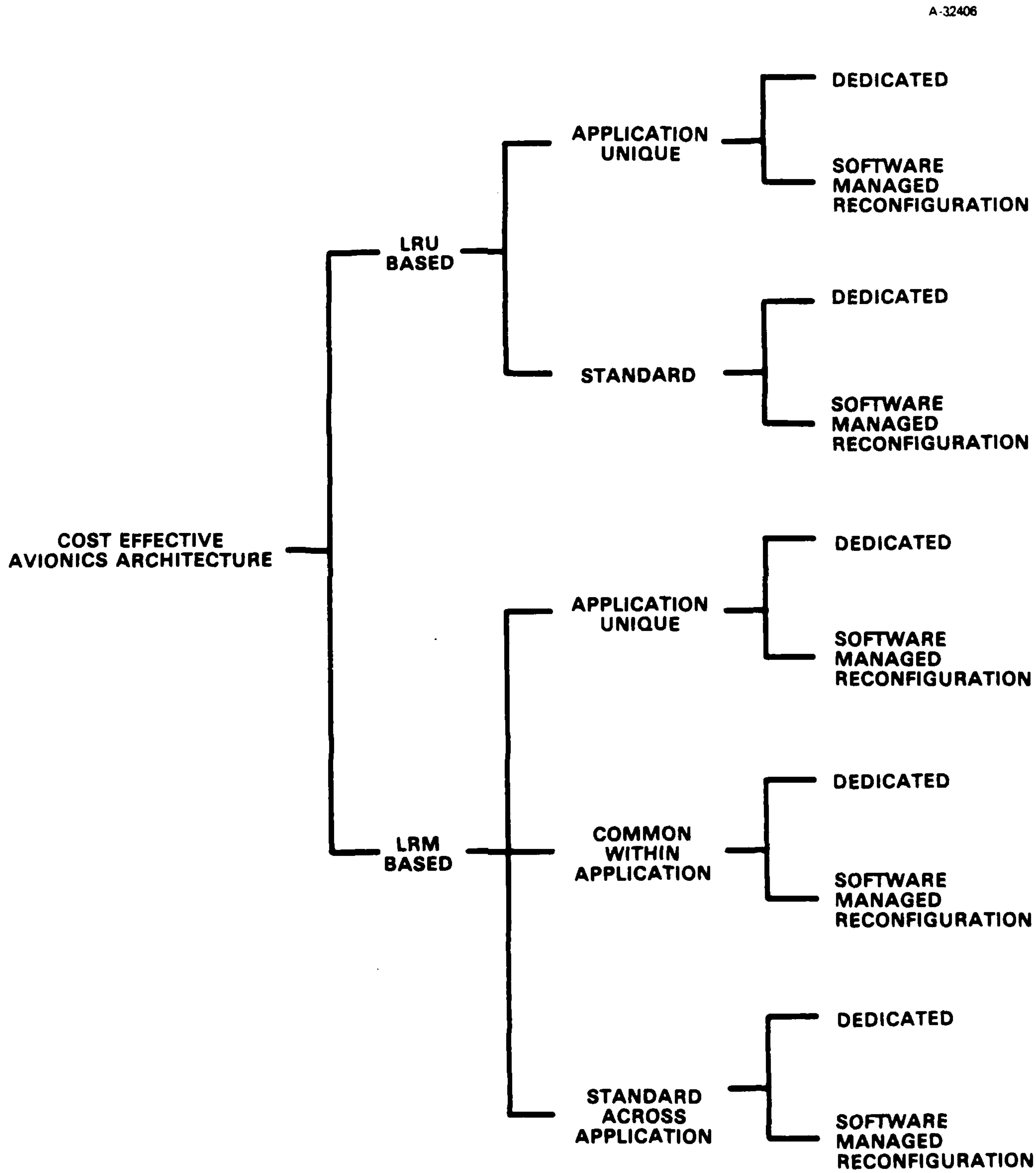

Figure 3.6-1 Modular Avionics Decision Tree

4. DECISION CRITERIA

The decision criteria by which an alternative is selected for inclusion in the preferred concept are developed and discussed in this chapter. The discussion is organized to follow the five major cost categories introduced in the previous chapter.

4.1 PROGRAM MANAGEMENT

4.1.1 Certification Facility

Figure 4.1-1 shows the decision tree for this factor.

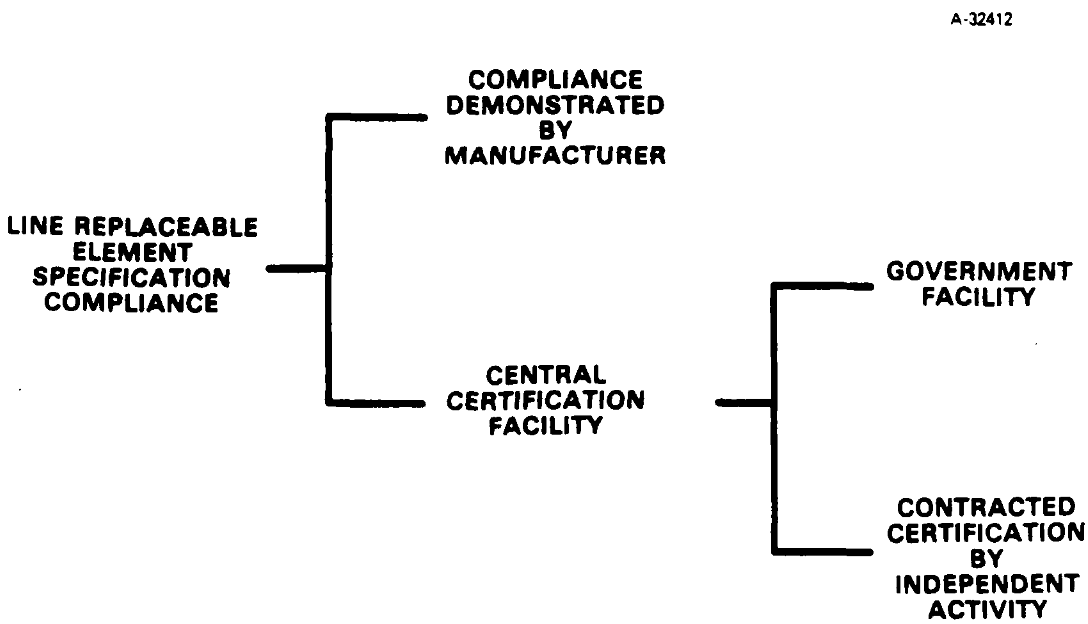

Figure 4.1-1 Certification Facility

Criteria - Cost, Government manpower, facilities/equipment, risk of non-compliance, risk of degraded quality assurance.

Discussion - The expected contribution to life cycle cost for a certification facility will be in manpower, facilities, equipment, and test program development. The Naval Weapons Support Center (NWSC) facility at Crane, Indiana is an example of what may be required to support a certification program. This facility occupies about 20,000 sq. ft. and has a staff of about 100 people. They presently test a combination of about 3000 SEM format A and B modules a year. Facility size and manpower will be dependent on the tasks to be performed such as the following accomplished by NWSC:

Specification Development

Design Verification

Initial Qualification

Periodic Check

Test Procedure Correlation

Manufacturer Audits

Change Control

Qualified Products List Maintenance

Failure Analysis.

Also to be considered is the type and extent of testing to be performed. Some of the factors to consider are:

Functional Tests - Digital and analog with automatic test equipment and bench equipment

Environmental Tests - Temperature, humidity, vibration, thermal shock

Failure Analysis - Scanning electron microscope, low power optics microscopes, disassembly tools

Test Development - Test jigs and software.

Some of the benefits to be gained are reduced risk of introducing a non-compliant element into inventory and a centralized data pool for element specification. A more important benefit to be gained with an extensive Quality Assurance Program would be higher module reliability and consequently a lower life cycle cost.

The investment in equipment for a facility similar to that at NWSC is estimated to be $10M, but the pay back is in improved production techniques, standardized test procedures, reduced development and test costs, which result from centralized development control. The alternative permitting the manufacturer to demonstrate compliance, will not introduce cost, but the potential for allowing non-compliant hardware into the inventory increases. The need for consideration of this factor increases when standard line replaceable elements are used.

4.1.2 Configuration Management Library

The decision tree for this factor is shown in Fig. 4.1-2.

Criteria - Cost, facilities, manpower, proliferation of configurations.

Discussion - If there is no ready source of standard unit data, compliance with standards may be lost and designers would have no way of determining if a standard unit fitting the design requirement is available. The various options have

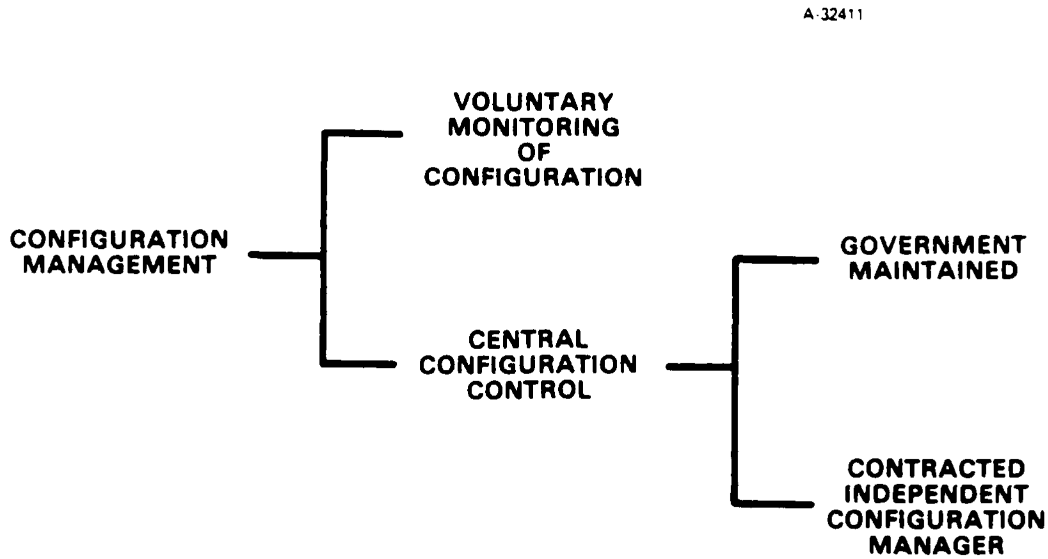

Figure 4.1-2 Configuration Management Library

differing implemention costs and varying probabilities of success. The costs for each alternative are to be developed. This factor is applicable only to concepts incorporating standard line replaceable elements.

If a data library is maintained, the cost of developing it and maintaining it must be evaluated with regard to the potential benefit to be derived. The benefit is not directly quantifiable in terms of savings to the Government. It is a service to the design community to facilitate the use of the standard units and to make their use the most cost effective procedure for the hardware designer. The Government can expect to realize cost savings through the widespread use of the standard design information. Questions to be resolved before estimating the cost of implementation include the formatting and release of the data. A Computer Aided Design (CAD) data base would offer significant advantages including easy access and efficient updating. The library facility could be small. The library staff would be required to update and maintain the file data on the computer. The cost of establishing and maintaining the facility by the Government, under contract to the Government, or by an independent organization should be developed.

4.2 DEVELOPMENT AND ACQUISITION

4.2.1 Product Performance Agreements

The decision tree is shown in Fig. 4.2-1.

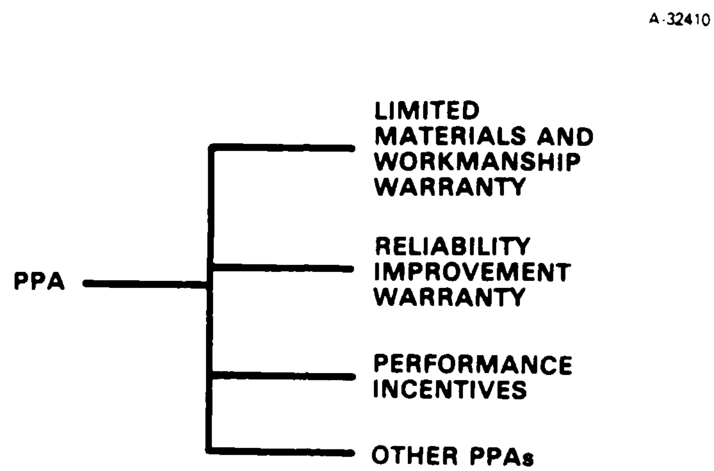

Figure 4.2-1 Product Performance Agreements

Criteria - Cost, performance, reliability.

Discussion - Due to the development status of this program there is insufficient data to support an in-depth quantitative analysis, although the various warranty approaches were reviewed for their applicability. For instance, any of the warranties which stimulate reliability growth, such as the RIW, appear too risky for this program. The basis for this reasoning is that new advanced technology which has no field or prior operational experience is likely to render the RIW a high risk option due to the high level of risk in estimating present reliability levels, reliability growth, and failure trends. There are also risks in the lack of knowledge about the operational environment, installation, and integration. The Government, and also the contractor in this case, should be aware of the risks and conduct further analysis to determine if an RIW is applicable. If an RIW is applicable, care should be taken to minimize the risks.

On the other hand, a warranty such as an MTBF-VT has reasonable applicability to the common module program. Generally, under the terms of an MTBF-VT the contractor guarantees a certain initial level of *field* MTBF. The field performance is determined by a verification test conducted by the user according to a testing scheme prescribed by the warranty. Verification test periods might begin six months after the nth unit is delivered and conducted at six month intervals during the warranty period. The guaranteed MTBF is usually increased during each test period so that the ultimate reliability goal is reached at or shortly before warranty expiration. When the contractor fails to meet a measurement goal, the Government typically receives consignment spares (at no additional cost) to improve system availability.

With the limited data available it appears that the MTBF-VT or a similar approach will meet the needs of the common module program. In addition to the basic warranty, a Correction of Deficiencies clause and a warranty on Materials and Workmanship will be required to fulfill the requirements of the law as stipulated in the 10 U.S. Code Section 2403 (10 USC 2403).

It is possible to estimate warranty cost on the basis of historical costs of avionics programs using advancing technology. At this point, the common module program appears to be a moderate to high risk program from a warranty perspective. Accordingly we estimate warranty cost at seven percent of recurring unit cost per year.

4.2.2 Competition

The decision tree is shown in Fig. 4.2-2.

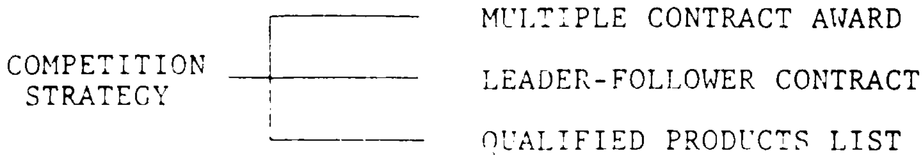

Figure 4.2-2 Competition

Criteria - Acquisition cost, quality, and production capacity.

Discussion - The costs of competition vary with the strategy employed. Logistics support costs will increase as the number of suppliers providing form, fit, and function compatible hardware that is not physically identical is increased. Tooling and test equipment such as interface test adapters and test program sets must be provided for each supplier's hardware. Government management costs increase with the number of separate contracts that must be managed. In the leader-follower contract case, the leader's hardware design is provided to the follower. The cost of providing the design information to the follower and follower startup costs must be assumed by the Government. The benefits to be achieved through competition include reduced acquisition costs and greater surge capacity in industry if production rate increases became necessary. Each individual supplier is more aware of his production efficiency and generally makes more cost effective decisions in the face of competition. Experience has shown that competitors are willing to make capital investments and introduce innovation into the production line to improve their competitive position. Quality and reliability of the product are more important to a manufacturer who may lose subsequent business if his product is not as durable as that of his competitor. There is no single strategy for competition, just as there is no single product performance agreement that is ideal for all procurements. The strategy must be evaluated with respect to the overall program objectives.

4.3 DESIGN

4.3.1 Partitioning

Figure 4.3-1 shows the decision tree for this factor. The criteria, shown in Table 4.3-1, used in evaluating the alternatives are discussed in the following paragraphs.

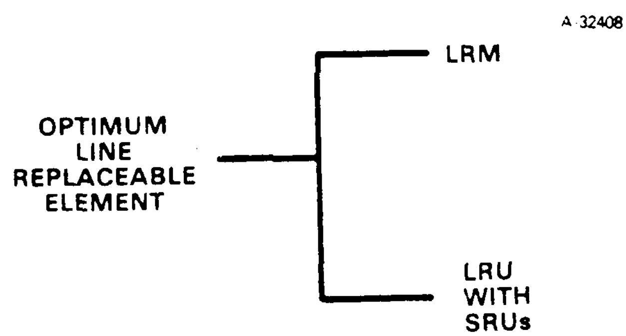

Figure 4.3-1 Partitioning

Discussion - An important constraint associated with partitioning is the need to detect and isolate faults to the module or unit during testing. If the ambiguity group includes more than one module, then more than one module must be removed, replaced, and sent through the repair pipeline. This constraint would tend to keep the module size sufficiently large to assure that the ambiguity group is no greater than one. As Fig. 3.3-1 indicates, the cost/failure-free operating hour must be kept

TABLE 4.3-1

PARTITIONING DESIGN CRITERIA

Program Management

- Manpower Costs

Acquisition and Development

- Development Cost
- Industry Support
- Schedule/Risk
- Interservice Applicability
- Acquisition Cost
- Competition
- Producibility

Design

- Space/Weight/Power
- Hardware Reliability
- Technology Independence
- Testability
  - Fault Isolation and Detection
  - Fault Tolerance
- Packaging
  - Thermal Management
  - Corrosion Control
  - Chemical Biological Warfare Protection
  - Electrical Overstress/Electrostatic Discharge Protection
  - Mounting Provisions

Operation

- Mission Reliability
- Ease in Adapting to New Missions
- Availability
- Deployment Costs
- Mission Performance

Support

- Spares
- Storage
- Handling
- Item Management
- Data Management
- Maintenance
  - Manpower
  - Facilities
- Support Equipment
  - Training
  - Technical Data
  - Maintenance

low to hold down the spares cost. If the unit is high in cost and low in reliability, the investment in spares to keep the pipeline flowing raises the life cycle cost. If the reliability of the module is sufficiently high, fewer spares are needed in the pipeline and the life cycle cost is reduced. These constraints tend to reduce the size of the line replaceable element in order to reduce complexity which in turn would reduce element cost and increase element reliability. Partitioned element size is also constrained by the information flow requirements across the element boundaries. Speed and noise constraints will tend to keep the elements sufficiently large to contain the high speed, low noise interfaces on a single element. Both VHSIC and monolithic microwave integrated circuitry are allowing the hardware size to shrink so that functions can be contained on practically sized elements.

Program Management - There is no apparent difference in cost between management of an LRU program or an LRM program if the standardization factor is not considered.

Development and Acquisition - The costs for developing and acquiring LRUs or LRMs should be similar. Packaging constraints associated with protecting the smaller LRMs may introduce added costs however. Assuming that the same level of technology is used for both the LRU and the LRM, there is no anticipated difference in risk. The smaller the functional element, the greater the potential for multiple uses within and between services. Given the same technology, either approach should be producible. Competition can help to hold acquisition costs down when the procuring agency continues to allow prospective bidders to propose solutions to requirements, rather than requiring exact design duplications.

Design - More space, weight and power may be required for an LRM implementation owing to the increase in individual module volume and weight to protect it in the handling environment. Hardware reliability may be reduced by the additional circuitry needed to implement OBT to the module level. For the LRU alternative, OBT must isolate only to the unit level unambiguously. Fault detection and fault isolation for both LRUs and LRMs are expected to be aided by the on-chip fault detection capabilities offered with VHSIC. Packaging constraints for the LRM are expected to add volume and weight to the overall functional element. Thermal management and corrosion control techniques are implementable for either LRUs or LRMs. Chemical/biological warfare protective measures are similar to corrosion control techniques in many respects when module provisions are compared. A conformal coating like PARALENE has been found to be effective in many cases but it is hard to remove for repair. In both the LRU and LRM configuration, the exposed interface connectors are vulnerable when the element is removed from the weapon system. Electrical overstress and electrostatic discharge protection may require bypassing/filtering of pins on the exposed connectors which would penalize the LRM more since there are more exposed element connectors to be handled than would be the case with an equivalent subsystem LRU.

Operations - From an operations point of view, the alternative with the most potential for eliminating the avionics intermediate shop must be given the advantage. Without considering the support costs, the reduced dependence on the AIS reduces vulnerability. It facilitates airfield deployment by eliminating the airlift requirement for the AIS. There is no apparent performance difference between LRUs and LRMs. The potential for mission reliability improvement increases as the number of common elements subject to interchangeability in flight increases. Both LRUs and LRMs can be configured to allow for redundancy but the potential for success is greater using LRMs, since the smaller functional elements are easier to replicate and use as common elements in a weapon system.

Support - Support costs are heavily influenced by the acquisition cost and reliability of the spare line replaceable elements. Since the LRM is smaller, the cost should be lower and the reliability higher, giving it an advantage in the support area.

4.3.2 Standardization

Figure 4.3-2 shows the decision trees for this factor. It should be noted that standardization can be used with LRMs or LRUs, therefore, costs must be developed for both LRMs and LRUs. The discussion includes the use of common modules within a weapon system.

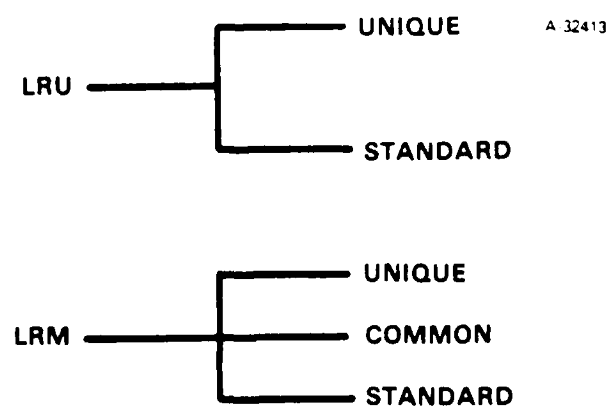

Figure 4.3-2 Standardization Decision Trees

Table 4.3-2 shows the decision criteria applied to this factor. A discussion of each of the five cost elements is included in the following paragraphs.

Program Management - Standardization brings with it a need for some centralization of control. Optional development of a certification facility and a configuration management library have been discussed separately, but regardless of these decisions, management costs can be expected to increase for standardization by the government. Much of the increase will be due to the added manpower to prepare and monitor the specifications and standards. Management of common elements within a weapon system would be the responsibility of the system integrator and would not affect government resources.

Development and Acquisition - Development costs can be expected to increase to cover additional compatibility testing required for standard hardware. Industry support for standardization is often withheld, or given reluctantly, due to the perception by industry that standardization by the government means another tier of requirements documents and a potential reduction in the opportunities to compete. The strategy must be developed carefully and then sold to the avionics industry in order to gain their support. The development of standardized hardware can be expected to take longer since there are more design constraints to factor into the process. Schedules may be at risk in the development phase. In follow-on acquisition of standardized hardware, the schedule risk should be less because the requirements have been well established and multiple sources for elements meeting those requirements are available. The potential exists for interservice applications where standardized requirements have been developed with the cooperation of the services. The smaller the functional partition of the elements, the more likely that interservice applications can be found.

TABLE 4.3-2

STANDARDIZATION DECISION CRITERIA

Program Management

- Manpower Costs

Acquisition and Development

- Development Cost
- Industry Support
- Schedule/Risk
- Interservice Applicability
- Acquisition Cost
- Competition
- Producibility

Design

- Space/Weight/Power
- Hardware Reliability
- Technology Independence
- Testability
  - Fault Isolation and Detection
  - Fault Tolerance
- Packaging
  - Thermal Management
  - Corrosion Control
  - Chemical Biological Warfare Protection
  - Electrical Overstress/Electrostatic Discharge Protection
  - Mounting Provisions

Operation

- Mission Reliability
- Ease in Adapting to New Missions
- Availability
- Deployment Costs
- Mission Performance

Support

- Spares
- Storage
- Handling
- Item Management
- Data Management
- Maintenance
  - Manpower
  - Facilities
- Support Equipment
  - Training
  - Technical Data
  - Maintenance

Producibility is a result of careful consideration of production needs during the design phase. Standardization of functional requirements may result in more mature design requirements meaning fewer last minute design changes where producibility may not be adequately considered.

Design - Standardization of hardware form, fit, and function implies that some design aspects must be compromised. Technology independence is maintained if standardization is restricted to form, fit, function and interface. Testability and packaging design become more complicated as requirements are introduced for standardization, but the effects are expected to be minor. The design of common elements within a weapon system offers the system integrator some of the advantages of standard hardware without the restrictions brought about by compatibility requirements for other systems. Design costs for the weapon system should be reduced with common elements.

Operations - The use of standard or common elements has little direct effect on hardware performance, consequently their use has little direct effect on mission performance.

Support - Common and standard flight hardware allows standard support equipment to be used. Savings in training brought about by the reduction in modules and reduced intermediate shop needs can be expected. Since the total number of elements is reduced through standardization, spares quantities will be reduced which will reduce all aspects of support cost including storage, handling and management.

4.3.3 Testability

The decision regarding testability is one of implementation. The decision tree in Fig. 4.3-3 has been simplified to show two alternatives, OBT versus off-equipment test. In fact, a combination of the two alternatives is a more likely outcome. OBT may be implemented with a software intensive solution or a hardware intensive solution. The hardware intensive solution will have the greater impact on physical characteristics like size, weight, and power. The software intensive solution may impact processor timing and sizing unless a dedicated processor is added.

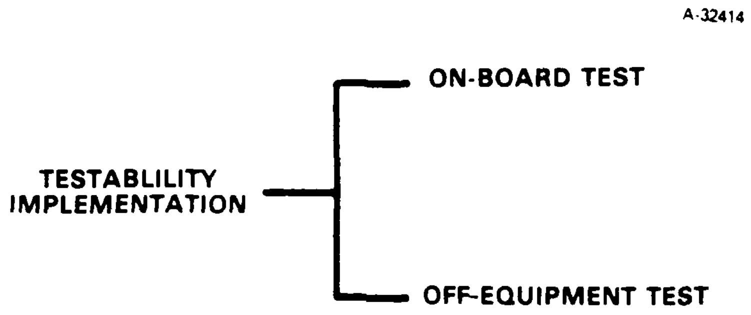

Figure 4.3-3 Testability

Table 4.3-3 shows the decision criteria for the testability factor. Each of the five categories are discussed in the following paragraphs.

Program Management - No impact to program management cost is anticipated since the testability features are included in the overall hardware/software design effort for OBT. Off-equipment testing requirements may generate additional support equipment needs that must be tracked.

Development and Acquisition - As the testability burden shifts to OBT, prime equipment development and acquisition costs can be expected to increase. Both hardware and software will be effected.

TABLE 4.3-3

TESTABILITY DECISION CRITERIA

Program Management
Manpower Costs
Acquisition and Development
Development Cost
Schedule/Risk
Acquisition Cost
Competition
Design
Space/Weight/Power
Hardware Reliability
Testability Characteristics
Performance Assessment
Fault Prediction
Fault Detection
Fault Isolation
Operation
Mission Reliability
Availability
Mission Performance
Support
Maintenance
Manpower
Facilities
Support Equipment
Training
Technical Data
Maintenance

Design - Space, weight, and power requirements will increase as a hardware solution to OBT is adopted. Estimates range from five to 35 percent of the available board space dedicated to OBT. The major functions to be performed by the adopted testability concept include:

1. Performance Assessment

Performance assessment of the avionics for the aircrew is an important task of OBT. The thoroughness of the test, the reliability of the test equipment, and the time it takes to complete the test are all criteria to be used in measuring performance of the concept. Since this performance assessment is expected to be performed in-flight, it must be performed by OBT.

2. Fault Prediction

Fault prediction is a task not normally performed for the avionics suite, but one that may be possible as advanced techniques are developed. Incipient engine fatigue failure is predicted based upon environmental exposure. It may be possible to predict incipient fatigue failures of avionics, based upon knowledge of accumulated exposure to environments. The effectiveness of a fault prediction capability may be determined by tracking the number of faults found between predicted failure-free intervals.

3. Fault Detection

It is important to be able to accomplish fault detection on-board the weapon system when it is used to initiate reconfiguration. Criteria to be applied in evaluating performance of the concept include the percentage of faults detected, the fraction of false alarms, and the mean time between failure. The can-not-duplicate rate, the mean fault detection time, the mean run time, and the mean time to repair are also important criteria.

4. Fault Isolation

Fault isolation is the fourth task to be performed by the testability concept. Criteria to be applied to the isolation task include test thoroughness, fault isolation resolution, fraction of false removals, fraction of faults isolated, retest OK rate, and mean time to repair. Fault isolation must be capable of locating the fault to within a line replaceable element to reduce the ambiguity group that might otherwise have to be removed on the flight line.

Operation - Testability impacts operations through its effect on mission reliability and availability. Availability is influenced by the mean time to repair which is driven by the testability concept.

Support - Maintenance manpower and facilities requirements increase as the testability concept uses off-equipment testing. Support equipment needs, including training, technical data, and maintenance are driven heavily by off-equipment test needs.

4.3.4 Time Stress Measurement Device (TSMD)

The objective to be met by the TSMD system must be established in order that it can be evaluated with respect to meeting the objective. Rome Air Development Center (RADC) and the Aeronautical Systems Division (ASD) have been cooperating in a program to define how the TSMD system might be used and to establish what data should be recorded. Some potential uses for the system include:

1. Product Performance Agreement (PPA) Support

This use may not justify the capital investment in data reduction facilities and in the impact on the equipment, since PPA's are typically applied for the first five years in the life of a new hardware development program. Performance or Reliability Incentive Agreements are useful for early design contracts, but such agreements would not impact reliability for follow-on reprocurements of existing designs.

2. A Source of Environmental Data For Use in Improving Future Designs

The reduction of data collected for this use could be done at a central location and it could be accumulated in batch quantities since time response is not critical. Information related to a specific aircraft would not be required. Statistically significant information on the fleet of aircraft could be gathered from selected instrumented aircraft.

3. An Environmental Data Source Used to Establish Hardware Retest or Replacement Intervals

This information is time critical and it should be correlated to a specific aircraft. For these reasons, the data reduction and interpretation should be done at each base. Scheduled maintenance based upon environmental exposure will be possible when fatigue failure mechanisms in electronic assemblies are better understood. The failure prediction capability could improve mission reliability and availability but the manpower workload for data reduction and interpretation at base level will increase.

The planned use of data will determine the estimated costs for implementing the TSMD system. The TSMD may be contained in a single chip on a sample of modules but the memory storage requirement, the method of retrieval of the data, and the reduction and dissemination of the results must be considered in the cost of implementation. Availability of environmental data in itself will not improve system performance. The program must include provisions for using the data to increase the hardware durability through design improvements.

The cost elements for a TSMD data reduction facility include:

(1) Staff - The base level manpower requirement is dependent upon the number of weapon systems being monitored and the form of the information being collected.

(2) Data Reduction Hardware - A playback device for the weapon system data and a computer based interpretation system will be necessary.

(3) Central Management Organization - An organization will be required to interpret and take action based upon the environmental data gathered.

The criteria to be used in evaluating these alternatives include the implementation cost and the expected benefit associated with knowledge of the environment. Knowing the environment after the design has been fielded will allow the effect of mission changes, for example, to be determined. It can be used as a tool to predict hardware reliability or failure-free periods between scheduled maintenance. If scheduled maintenance is not anticipated to be an option, the knowledge of the environment must be used to identify weak designs for product improvements.

4.3.5 Software Development for a Dynamically Reconfigurable Architecture

Reconfiguration is a means of improving mission reliability. However, the hardware reliability is not improved and if the maintenance philosophy is such that hardware failures are to be corrected when they are identified, the maintenance burden may not be reduced and the overall operation and support costs may remain high. The decision tree for software development for reconfiguration is shown in Fig. 4.3-5.

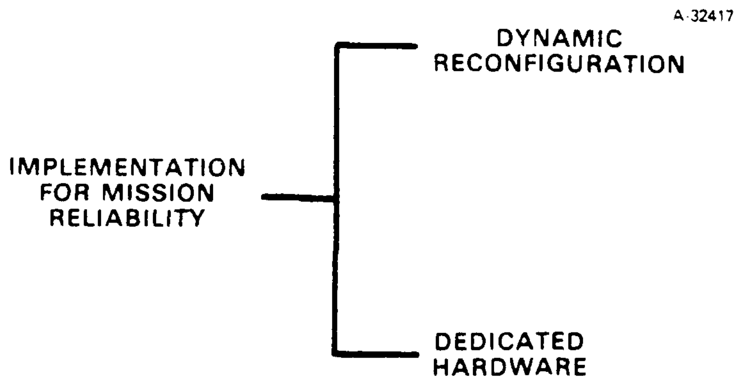

Figure 4.3-5 Reconfiguration Software

The decision criteria used for evaluation of the alternatives must focus primarily on the life cycle cost of each option. Development costs of the software associated with the dynamic reconfiguration alternative are expected to be sizeable, but operation and support costs should be low. When dedicated hardware is used to achieve required reliability levels through redundancy, the redundant hardware must be supported over the life cycle. Reconfiguration assumes that the processors are sufficiently common to allow operational flight programs to be run interchangeably.

4.4 SUPPORT

4.4.1 Modular Automatic Test Equipment (MATE)

The use of MATE for support equipment needs should be evaluated with respect to alternative means of achieving the same results. The decision criterion is the influence on life cycle cost associated with using MATE. As the testability concept shifts toward OBT, less intermediate level test equipment is required. As the need for external test equipment is reduced, the life cycle cost impact of using MATE is correspondingly reduced.

4.4.2 Integrated Maintenance Information System

The decision to implement IMIS must be made on the basis of life cycle cost impacts to the weapon system in relation to projected improvements in mean-time-to-repair in using the automated technical data. The impact on maintenance efficiency becomes less important as hardware reliability increases and OBT successfully isolates to the faulty element. The IMIS concept has yet to be proven in the field so there is some risk associated with its incorporation.

4.4.3 Depot Repair Facility

The decision tree in Fig. 4.4-1 shows the alternatives to be considered.

The criteria used in selecting the preferred alternative includes the following:

1. Life cycle cost of staffing and maintaining the depot

2. Contract cost for contractor maintenance facility

3. Cost of returning parts to the vendor for repair

4. Expected failure rate of the avionics hardware to be repaired

5. Turnaround time on repairs

6. Surge capability in time of conflict.

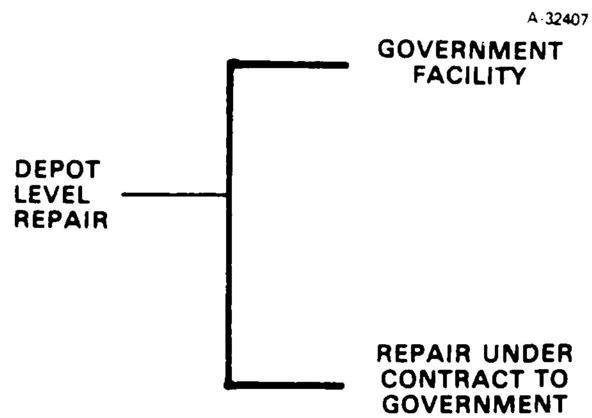

Figure 4.4-1 Depot Repair Facility

The avionics hardware reliability plays a significant part on this decision. If the hardware reliability is sufficiently high, the largely fixed cost of the depot repair facility could be higher than the equivalent repair capability performed under contract as required. Potentially in some instances, reliability could be so high and production cost so low, that the modules could be thrown away upon failure. Capabilities of a certification facility should be considered when deciding on a depot repair facility. Surge capability in time of conflict must also be considered in the decision. As the functional complexity of the line replaceable element is reduced, the available industrial base capable of performing the repair expands. LRMs for example would be more appropriate for contracted depot repair than LRUs. Standardization of the elements will expand the manufacturing base and the potential contract maintenance facilities thus improving surge capability in time of conflict.

4.4.4 Maintenance Strategy

Maintenance alternatives that may be considered for use with modular avionics include the scheduling of preventative maintenance versus the use of maintenance on demand, as traditionally practiced with aircraft avionics suites. Figure 4.4-2 shows the alternatives being considered.

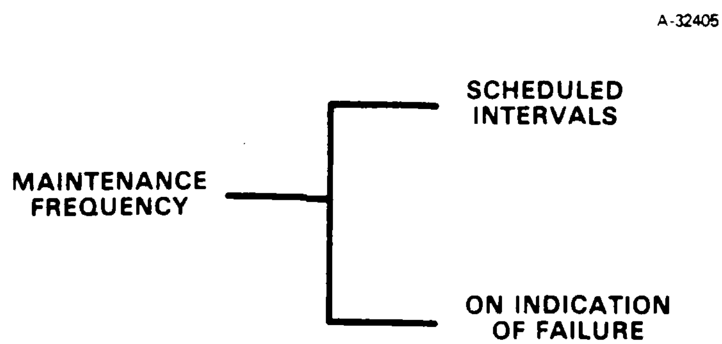

Figure 4.4-2 Maintenance Strategy

The decision criteria to be considered in selecting the alternatives include:

1. Mission reliability
2. Hardware reliability
3. Operation and support cost.

As the predictive capability of OBT improves and the understanding of avionics hardware failure mechanisms increases, it may be possible to identify expected intervals between fatigue failures in avionics hardware. It will be possible to set maintenance intervals shorter than the expected failure free interval so that the line replaceable element can be removed, inspected, and recertified for a new failure-free interval. Such use of scheduled maintenance could significantly improve mission reliability and system availability. Operation and support costs may be reduced by reducing unscheduled maintenance demands. Scheduled maintenance may require environmental data from the TSMD to provide the detailed knowledge of environmental exposure necessary for failure predictions.

5. SCENARIO DEVELOPMENT

It is necessary to make assumptions regarding systems characteristics and an operating environment in order to use simulation models to conduct a cost/benefit study. This operating environment and the system description form the scenario in which the study is conducted. In planning studies such as Air Force 2000, the support requirements are predicted to change in order to adapt to a much more dynamic battlefield environment. Mobility, flexibility, and survivability must be built in to the support system. This forces decentralization of the support structure with more reliance on self-contained diagnostics including detection and isolation of faults. There will be fewer main support bases and they will be located well out of the combat area. The main support bases will supply operating bases from which aircraft will deploy to dispersed operating locations. Autonomous operations from these locations would be expected without relying on the support equipment typical of present fighter aircraft. A modular avionics architecture could be utilized on fighters, transports or bombers in the planned scenario, but the worst case scenario would be that of the fighter aircraft. In most planning scenarios, the transports and bombers would not be operating from the austere dispersed operating locations that would be expected of the fighters. The fighters generally have more rigorous avionics requirements brought about by size limitations driven by performance and radar cross section requirements. Single engine propulsion systems make control electronics flight critical and thermal management is more difficult to achieve when cooling capability is carefully budgeted. The offensive and defensive fighter avionics present a formidable challenge to the integrator who must fit the avionics hardware into the available space. Present fighter aircraft will serve as the most appropriate information base to use in the simulation. Today the typical fighter aircraft completes approximately 250 sorties per year. Each sortie lasts approximately 1.5 flight hours. As noted in the background information, the aircraft of the 1990s will be expected to have a sortie surge rate of up to five per day and each of the sorties could last as long as four hours.

5.1 AVIONICS ARCHITECTURE BASELINE

The avionics architecture for mid 1990s application has not yet been defined, but research into some of the desirable characteristics of the architecture for tactical aircraft has been underway for some time. The avionics suites of aircraft like the F-15E or F-16C/D aircraft offer the most substantial information applicable to mid-1990s fighter requirements. Current laboratory development work on systems such as the ICNIA, URR, CSP, and the VHSIC MIL-STD-1750A Processor (V1750A) serve as the partitioning reference for much of the module estimation.

In order to formulate a baseline for the study, the general architecture shown in Fig. 5.1-1 has been assumed. Although it does not represent the architecture of any aircraft, it will serve as the basis for development of line replaceable element counts for cost estimating. LRUs or LRMs could be used as the hardware building blocks to fabricate the avionics suite. For purposes of the study, the module types

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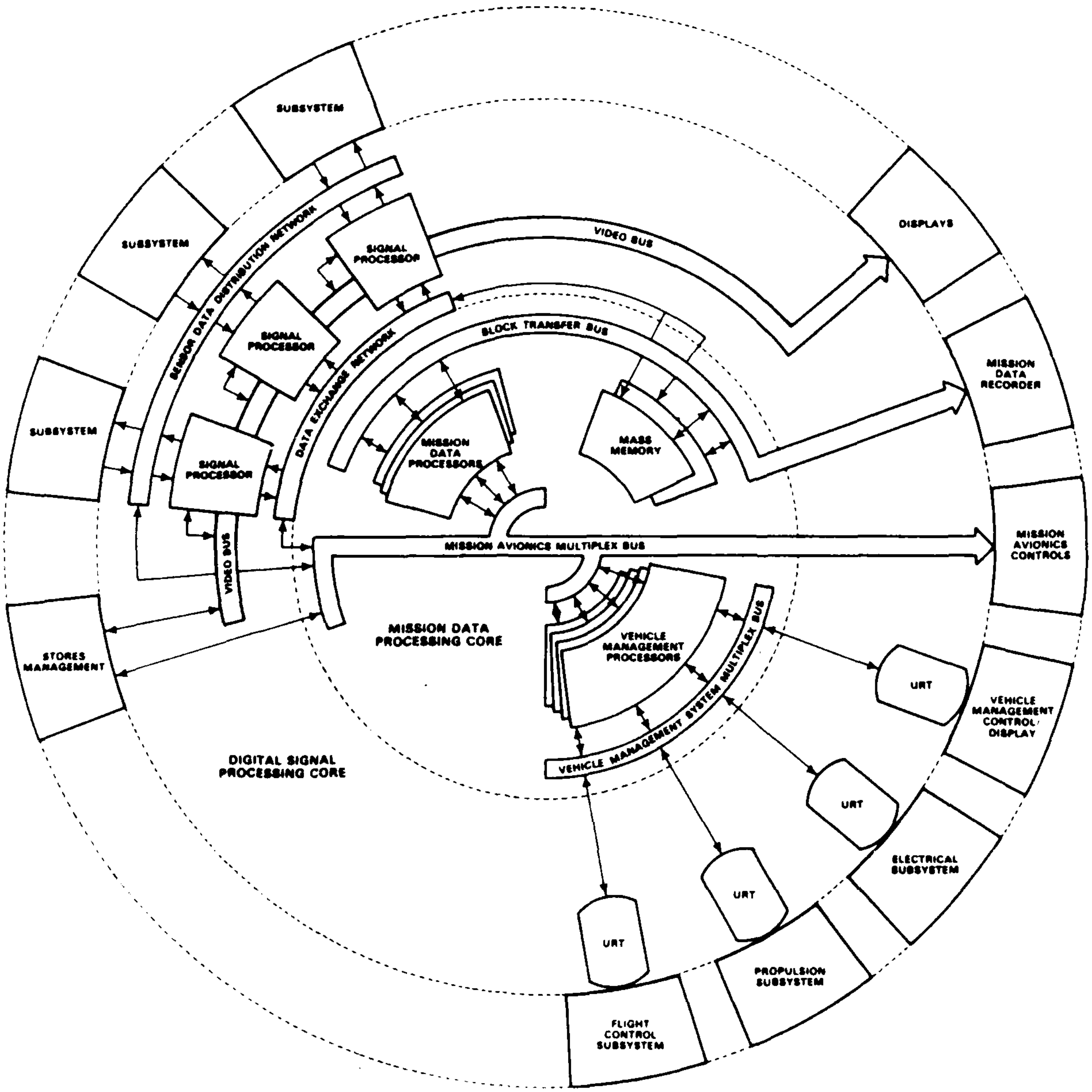


Figure 5.1-1 Modular Avionics Architecture

to be used as the basic elements are shown in Table 5.1-1. The LRUs are then formed from combinations of the LRMs and packaged in a MIL-STD-1788 standard package. The use of three integrated racks is assumed for the suite of LRMs. The tasks performed by the avionics suite, based upon current tactical fighter requirements, are shown in Table 5.1-2.

TABLE 5.1-1

BASELINE COMMON MODULE SET

1. 1750A DIGITAL PROCESSOR/CSP ESU
2. AVIONICS BUS INTERFACE
3. SHARED MEMORY MODULE/CSP GLOBAL MEMORY
4. OPTICAL NETWORK INTERFACE/SENSOR INTERFACE
5. VIDEO MODULE/CSP VIDEO INTERFACE
6. COMPLEX VECTOR PROCESSOR MODULE
7. FLOATING POINT PROCESSOR ELEMENT
8. MASS MEMORY
9. MIL-STD-1553 I/O MODULE
10. IEEE 488 I/O MODULE/USER GUIDE CONSOLE INTERFACE
11. MIL-STD-1760 STORES I/O MODULE
12. DEDICATED INTERFACE MODULE
    - ANALOG/DIGITAL
    - DIGITAL/ANALOG
    - DISCRETES
    - SERIAL CHANNEL (IN AND OUT)
13. CSP FLOATING POINT PROCESSOR ELEMENT
14. CSP SORT ENHANCED PROCESSOR ELEMENT
15. CSP DATA NETWORK
16. VECTOR PREPROCESSOR
17. IMAGE PROCESSOR
18. BI-PHASE CORRELATOR

TABLE 5.1-2

AVIONICS TASKS

Communication Navigation Identification		
UHF Comm	IFF Transponder	Intercom
VHF Comm	IFF Interrogator	TACAN
ILS/Flight Director	INS	
Vehicle Management		
Flight Control	Engine Inlet Scheduler	
Air Data	Engine Control	
Radar		
Antenna	Signal Processor	
Receiver/Transmitter	Computer	
Electronic Warfare		
Dispensers	Electronic Warfare Warning	
Radar Warning	Tactical Jamming	
Mission Area		
Fire Control	Stores Management	
Cockpit Video	Electro Optical	

When this task grouping is translated into modules required, the quantities shown in Table 5.1-3 result. For the LRU analysis, the modules should be repackaged into an appropriate number of LRUs, each containing an avionics bus interface module and a power supply module. An initial partitioning estimate for the number of LRUs to be included in the baseline study is 60. This may be varied as more data on the specific suite to be simulated is collected during the study effort.

TABLE 5.1-3

REQUIRED AVIONICS MODULE COMPLEMENT

SENSORS/	INTEGRATED RACK #1	INTEGRATED RACK #2	INTEGRATED RACK #3
1. ICNIA RF #1	Avionics Power Supply	Avionics Power Supply	Avionics Power Supply
2. ICNIA RF #2	Optical Network	Optical Network	Optical Network
3. INS #1	Avionics Bus Interface	Avionics Bus	Avionics Bus
4. INS #2	Optical Network	Optical Network	Optical Network
5. Electronic Control	Avionics Bus Interface	Avionics Bus Interface	Avionics Bus Interface
6. Pneumatic Sensor	Optical Network	Optical Network	Optical Network
7. Radar Antenna	Video Module	Video Module	Video Module
8. Low Power RF	Floating Point PE (8)	Floating Point PE (2)	Floating Point PE (2)
9. Radar Rec/XTR	1750A DP (2)	Sort Enhanced PI (4)	V1750A DP (2)
10. Chaff Dispenser	Element Supervisor (8)	1750A DP (2)	Element Supervisor (4)
11. EW Receiver	Global Memory (4)	Element Supervisor (6)	Global Memory (2)
12. EW AMP	Data Network (8)	Global Memory (2)	Data Network (4)
13. EW AMP	Avionics Bus Interface	Data Network (8)	Avionics Bus Interface
14. EW AMP	1750A DP	Avionics Bus Interface	NV 1750A
15. RIU - Stores	Avionics Bus Interface	NV 1750A DP	Optical Network Interface
16. RIU - Stores	Avionics Bus Interface	Avionics Bus Interface	Mass Memory
17. RIU - Stores		Avionics Bus Interface	Avionics Bus Interface
18. RIU - Stores		Avionics Bus Interface	NV 1750A DP
19. HUD		NV 1750A DF	Avionics Bus Interface
20. Display		Avionics Bus Interface	Avionics Bus Interface
21. Display		Avionics Bus Interface	Avionics Bus Interface
22. Display		VMS Power Supply	NV 1750A DP
23. Control		Avionics Bus Interface	Avionics Bus Interface
24. Control			Avionics Bus Interface
25. Control			VMS Power Supply
26. CVTS			Avionics Bus Interface
27. CVTS			
28. Intercom			
28 LRU/195 SRU	41 LRMs	41 LRMs	35 LRMs

5.2 ELEMENT DESCRIPTION

The module count is sensitive to size allowances. A 5.88 x 6.4 inch card size is used as the baseline. Multiple printed wiring boards (PWBs) with varying pitch (or thickness) requirements are permitted as a module. The line replaceable elements are assumed to be protected from electrostatic discharge (ESD), electrical overstress (EOS), electromagnetic interference (EMI), and the handling environment. Conduction cooling to the siderails is used in the baseline module. It is anticipated that size may have a significant influence on life cycle cost so element size may be varied during the sensitivity analysis to measure the influence on life cycle cost. IBM has projected the relationship between the total number of modules required, and the size of the module, in work done in conjunction with their CSP contract. This relationship, shown in Fig. 5.2-1, may be used in the sensitivity analysis.

5.3 OPERATIONS AND LOGISTICS SCENARIO

The operational environment includes the number of bases, their location, and the number of aircraft supported at each base. Many models that might be used in the analysis consider the base location in two categories:

(1) Within the continental U.S., (CONUS)

(2) Overseas.

The transportation costs for pipeline spares is simulated as a fixed amount for each category. The aircraft to be considered in the scenario will enter the inventory

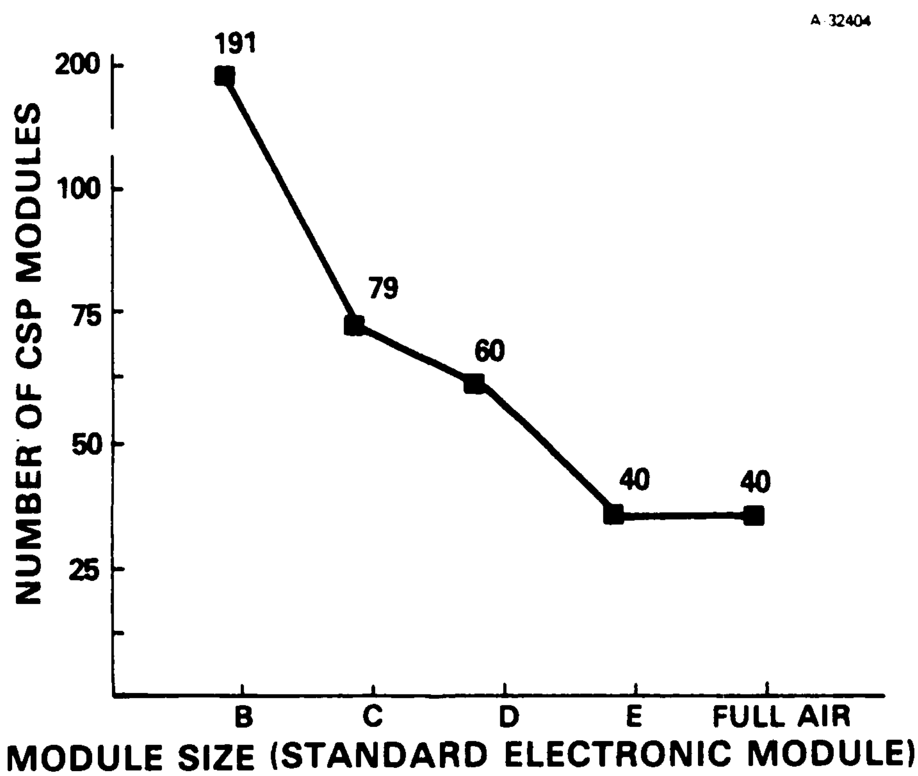


Figure 5.2-1 Number of Modules Required Versus Module Size

according to the acquisition and production schedule shown in Fig. 5.3-1. The acquisition schedule assumes a development phase for the preferred modular avionics concept which spans approximately two years before production planning for the first deliveries begins. For the scenario, the F-16 basing scheme has been adopted. The simulation should use 8 CONUS wings and 6 overseas wings. Bomber and transport quantities will be assumed to build at approximately the same rate as is currently being maintained.

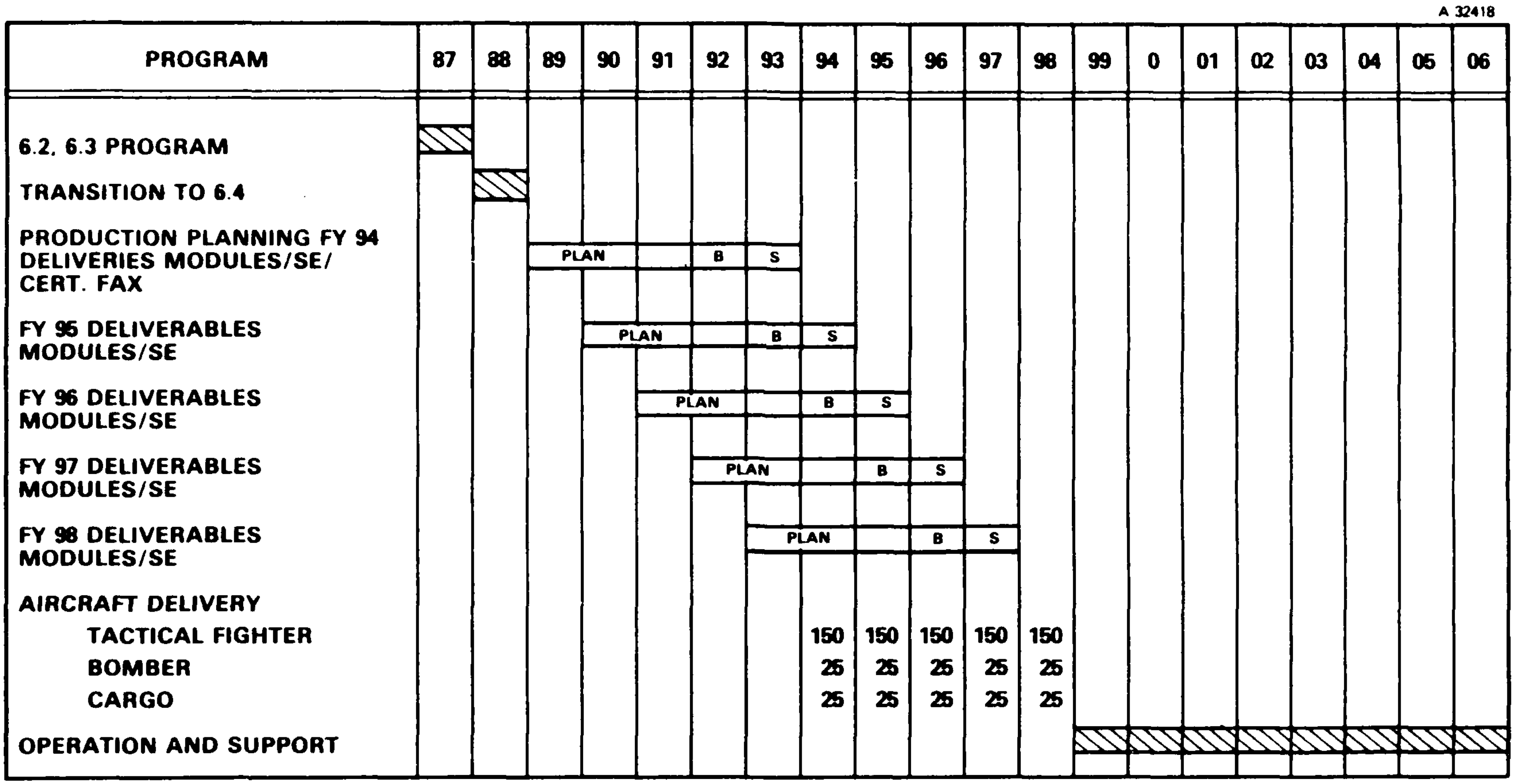


Figure 5.3-1 Modular Avionics Acquisition Schedule Baseline

The system support environment and the structure of each maintenance level form the logistics support scenario. Since the decision criteria for the partitioning option includes the ability to eliminate the intermediate maintenance level, both two-level and three-level maintenance options should be included. Figure 5.3-2 shows a simplified three-level maintenance model where LRUs are repaired by replacing SRUs at the intermediate maintenance level (I-level). The use of an AIS will be assumed for this level. SRU and LRU spares are stocked at I-level. SRUs removed at I-level are sent back to depot for repair or condemnation. The long pipeline between I-level and depot is filled with SRUs and the sparing policy focuses on SRUs.

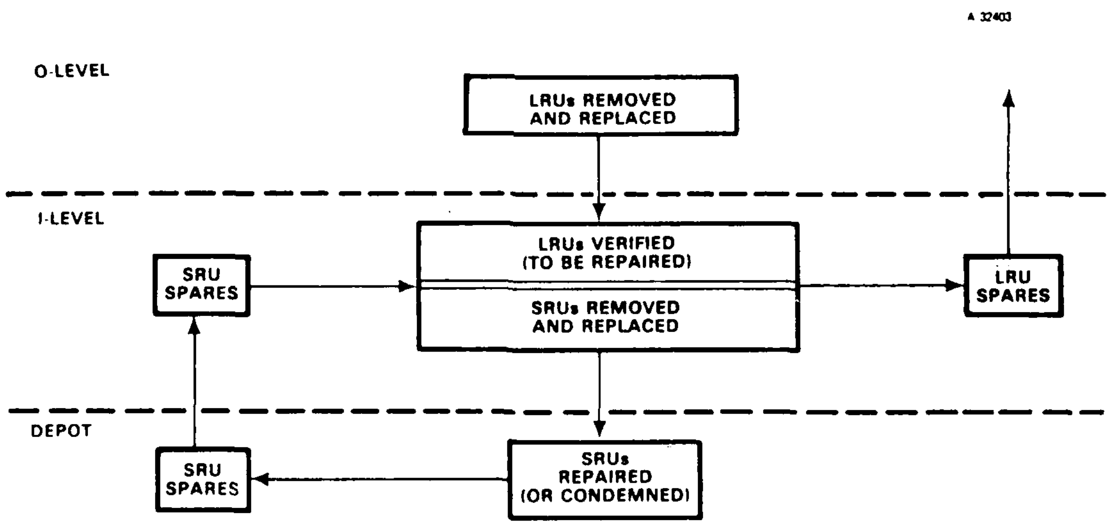


Figure 5.3-2 Simplified 3-Level Maintenance Model

A two-level maintenance model is shown in Fig. 5.3-3. Both LRU and LRM spares are stocked at the organizational level (O-level). There is no AIS in this arrangement. The long pipeline between O-level and depot is now populated with either LRUs or LRMs. The sparing policy focuses on LRMs. The support cost in either of the maintenance models is dependent upon the number and cost of the elements flowing through the long pipeline.

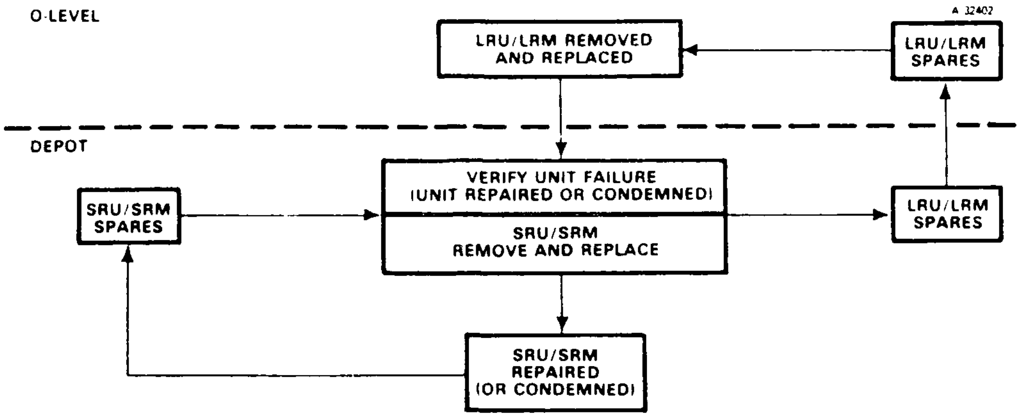


Figure 5.3-3 Simplified 2-Level Maintenance Model

Important support cost drivers in addition to spares cost are direct labor charges for repair. These charges include replacement activities at each maintenance level and capital investments for the AIS, AIS support equipment, AIS spares, and AIS facilities. The AIS facilities include shelters, generators, tools, and other associated items. Since direct labor is a function of unit reliability, it can be estimated when the reliability has been defined.

For the cost analysis, each of the options should be evaluated using both the two level and the three level models. A realistic implementation of line replaceable elements may require use of both two level and three level maintenance. High failure, high cost elements would be maintained using three levels while all remaining elements would be maintained using the two level concept. In this case, a reduced AIS capability would be retained in the field but the cost estimate would be reduced to reflect the reduced effort at the intermediate level.

6. ANALYSIS METHODOLOGY

This cost/benefit study has been formulated to aid decision makers in selecting a preferred modular avionics architecture concept. The factors influencing the formulation of the concept have been discussed in Chapter 3. These factors include optional features that must be evaluated using the decision criteria developed in Chapter 4. The impact on the life cycle cost of the system must be considered for each of the alternative decisions. Because of the interactions among features it is not always possible to develop an independent cost estimate for one feature alone. For example, the characteristics of the OBT utilized may influence the results of the life cycle cost analysis when the Integrated Maintenance Information System is implemented. The life cycle cost of the system incorporating both features may be less than the cost of either feature evaluated separately. However, some factors will be able to be treated independently. The certification facility, for example, may not directly influence element performance or reliability in any quantifiable manner. It will only reduce the risk of introducing non-compliant elements into the inventory. The certification facility may be treated as an independent factor for which the investment cost necessary to implement and maintain it would be estimated.

It will be necessary to develop life cycle cost estimates for all combinations of the dependent factors unless further simplifying assumptions are made. It may be possible to select the primary alternatives in sequence without considering the influence of all associated factors. This strategy would require that the analyst disregard some interactions among factors that would be expected to be minor in order to reduce the combinations of factors that must be evaluated to determine the preferred modular avionics concept.

To make intelligent acquisition decisions regarding the selection of modular avionics, it is necessary to look beyond the immediate cost of developing and producing the avionics. What may appear to be an expensive alternative among competing architecture concepts may be the least expensive when operation and support costs are considered. For this reason, it is necessary to consider the life cycle cost when making decisions. It should be noted that LCC is not the same as Operating and Support (O&S) cost, but rather includes O&S as an element of cost. The modular avionics LCC has been captured when the estimate includes the cost to develop, produce, operate, and support it. Figure 6-1 illustrates the LCC equation. LCC elements follow the modular avionics life cycle and often overlap as Figure 6-2 demonstrates.

DEVELOPMENT COST + PRODUCTION COST = PROGRAM ACQUISITION COST

OPERATING COST + SUPPORT COST = OWNERSHIP COST

PROGRAM ACQUISITION COST + OWNERSHIP COST = LIFE CYCLE COST

Figure 6-1 Life Cycle Cost Equation

Development costs include all costs required to develop the modular avionics prior to a commitment for production. This includes the cost of engineering design, the manufacture of test sets, and testing to prove the design. The development costs include all contractual and Government costs incurred to conduct and support the following:

- Basic and Applied Research
- Engineering Studies and Analysis
- Exploratory and Advanced Development

  Selection of materials, components, processes

  Engineering, design, fabrication, manufacture, and test of engineering models of system components and related support

- Full Scale Development

  Engineering, design, fabrication, manufacture and test of development articles and related support

  Government test and contractor support

  Software development

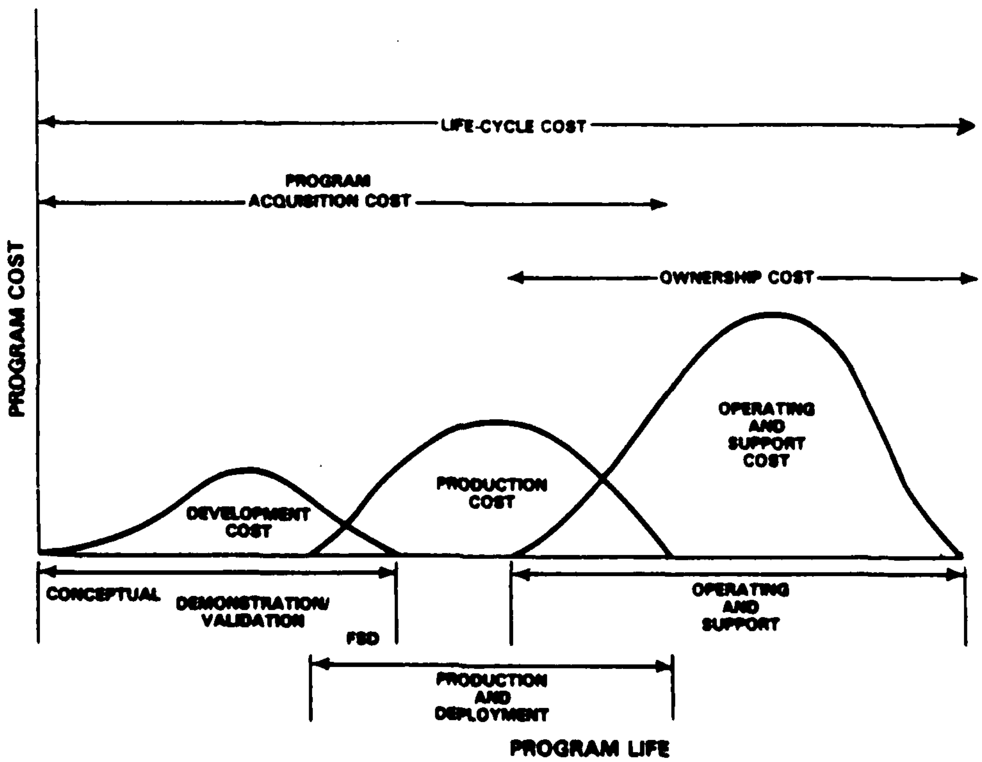


Figure 6-2 Modular Avionics Life Cycle Flow

Production costs include the costs associated with the fabrication, assembly, and delivery of the modular avionics. Obviously the number and complexity of components for a particular alternative will be a major production cost driver. Production costs are, however, a minor portion of the total LCC of modular avionics.

The most important costs in the modular avionics life cycle are the ownership (operating and support) costs. Although some avionics components may not have a 20 year lifetime assumed for LCC analysis, due to technological improvement or future risk factors, the ownership costs must be determined on a standard basis. These costs start with the modular avionics delivery and continue throughout the operational life. The ownership costs are summarized as:

- Operational personnel cost
- Maintenance personnel cost (differing for LRU or LRM approach)
- Maintenance material and facilities cost
- Ground support equipment cost
- Base operating support cost
- Transportation (pipeline) cost
- Personnel training cost

The computation of LCC requires:

(1) Hardware configuration description

(2) Operations and logistics scenario

(3) Defined system life cycle

(4) Associated development and investment activities.

- Basic and Applied Research
- Engineering Studies and Analysis
- Exploratory and Advanced Development

  Selection of materials, components, processes

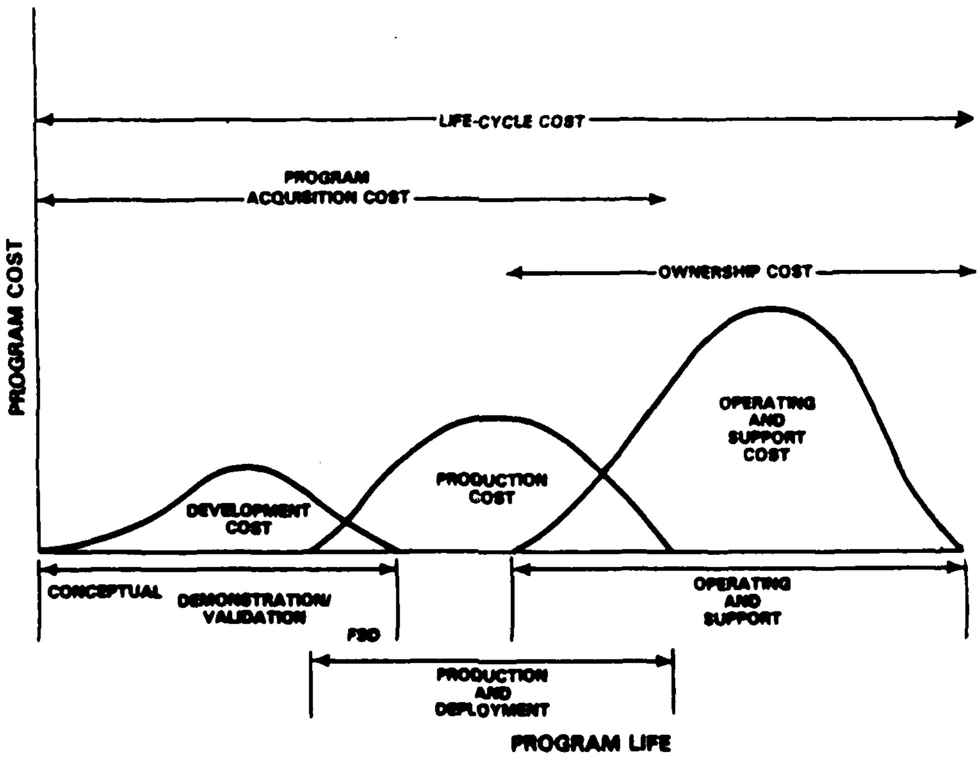
  Engineering, design, fabrication, manufacture, and test of engineering models of system components and related support

- Full Scale Development

  Engineering, design, fabrication, manufacture and test of development articles and related support

  Government test and contractor support

  Software development



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- Transportation (pipeline) cost
- Personnel training cost

The computation of LCC requires:

(1) Hardware configuration description

(2) Operations and logistics scenario

(3) Defined system life cycle

(4) Associated development and investment activities.

The hardware description has been outlined in the scenario development section, but additional definition may be required to tailor the information to the analysis model being used.

The operations and logistics scenario was established in the last chapter, but it may be modified as required during the analysis of alternatives.

A period of 20 years for the avionics life cycle is appropriate for analysis, although technological advances and changes in the nature of the threat can sometimes be expected to force avionics changes in a shorter time period.

The program acquisition (development) activities are generally not modeled in most LCC models so it is necessary to develop estimates off-line for input of program acquisition costs to the LCC models.. Where it is necessary to do so, the cost elements should be estimated using the general process outlined in Fig. 6-3. In practice a combination of three methods is used:

(1) Bottom-Up Approach

> Each cost element in the process (i.e., development engineering, printed wiring board fabrication, etc.) is estimated and the aggregate sum represents the cost.

(2) Analogy

> The known cost of a similar system is modified appropriately to account for differences and the result serves as an estimate of the analyzed system cost.

(3) Parametric Analysis

> An analysis based upon a minimum number of characterizations (such as size,

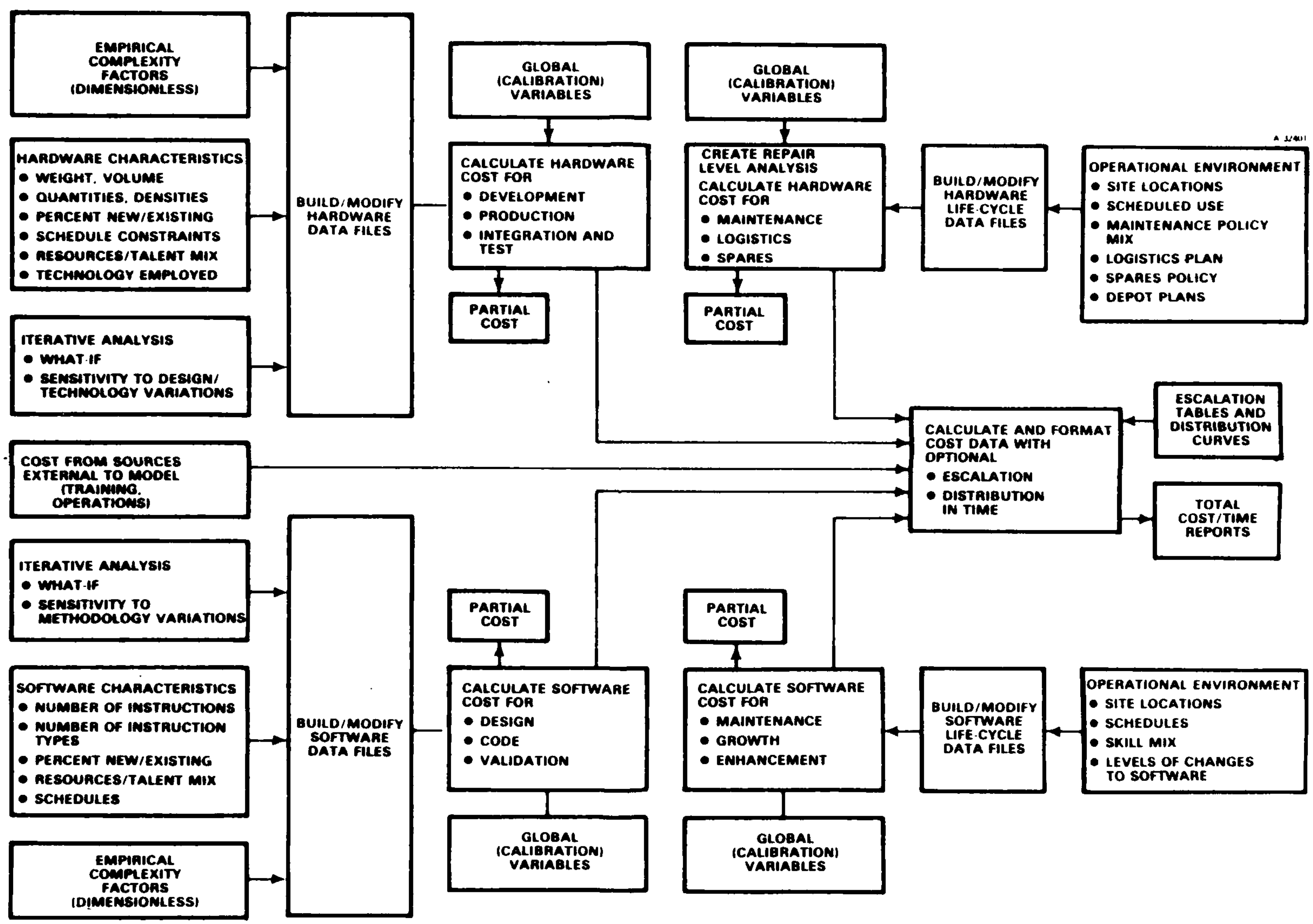

Figure 6-3 Cost Estimate Process: Flow Organization for System Trades

weight, lines of code, etc.) to estimate cost based upon a large stored data base. RCA Price Models utilize this type of analysis.

Since it will be necessary to make determinations of the system LCC for each combination of factors, a flexible simulation model is most appropriate. The models used should accommodate the introduction of a product performance agreement and should be able to simulate the effect that standardization of hardware across weapon systems has on LCC. A review of the decision criteria established for the alternatives shows that insight into the ownership (operating and support) costs will be important for decision makers. Typical detailed ownership costs include:

- Spares acquisition
  - Base level
  - Depot
  - Condemnation
- Support equipment acquisition
- Flight line level maintenance cost
- Base intermediate level maintenance cost
- Depot level maintenance cost
- Training
- Technical data acquisition
- Item management
- Data management
- Packaging and shipping
- Support equipment maintenance
- Transportation
- Shop spare
- Inventory storage
- Deactivation costs

Flexibility will be necessary in order to model the effect of each combination of alternatives in the simulation.

7. CONCLUSIONS

This study was commissioned to formulate an approach to evaluate alternative features of a modular avionics architecture concept for the mid-1990s. Review of background information shows that the operational support environment will be characterized as mobile, flexible, and austere. The support of avionics in the next decade must be more autonomous with less reliance on well equipped secure support bases close to the battlefield. The avionics required on the aircraft continues to increase while the available space shrinks in order to reduce radar cross section and to increase maneuverability. Cost of avionics acquisition and support must be controlled as the role of avionics expands and reliance on external support is reduced. The criteria by which each alternative feature is measured includes, therefore, the impact on system life cycle cost and the contribution to readiness or mission reliability.

The alternatives to be considered in a cost/benefit study have been identified and the decision criteria to be used in selecting them for inclusion in the preferred avionics concept have been developed. It has been necessary to establish a baseline scenario using available information on the aircraft and avionics expected to be used in the next decade. The research work on advanced avionics architectures using VHSIC technology sponsored by the laboratories at Wright-Patterson AFB has been used to construct an avionics suite for use in the study. The baseline architecture is described for a fighter aircraft since it represents a worst case application of the modular avionics concept. Phase I VHSIC with 1.25

micron feature size is used where possible in the module designs since that is the technology used in the design process today that will be in the field in the mid-1990s.

Interaction among the factors will make it difficult to establish a modular avionics program unless a careful evaluation is made of combined factor effects. For example, the use of effective OBT coupled with reliability improvements in the line replaceable elements may make it possible to eliminate the intermediate maintenance shop. With the intermediate shop gone, the benefits of programs such as MATE and IMIS are expected to be reduced. The costs must, therefore, be developed for each combination of factors to be considered.

The analysis methodology to be used in the study has been discussed with regard to the desirable characteristics of a simulation model to be used in developing the life cycle costs. These costs can be used in completion of evaluation tables similar to that shown in Table 7-1.

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ALTERNATIVE / COSTS	LRU BASED								LRM BASED											
	UNIQUE				STANDARD				UNIQUE				COMMON				STANDARD			
	DEDICATED		RECONFIG.		DEDICATED		RECONFIG.		DEDICATED		RECONFIG.		DEDICATED		RECONFIG.		DEDICATED		RECONFIG.	
	2 LVL	3 LVL	2 LVL	3 LVL	2 LVL	3 LVL	2 LVL	3 LVL	2 LVL	3 LVL	2 LVL	3 LVL	2 LVL	3 LVL	2 LVL	3 LVL	2 LVL	3 LVL	2 LVL	3 LVL
SPARES																				
MAINTENANCE MANPOWER																				
MAINTENANCE FACILITY																				
DEPLOYMENT																				
TRAINING																				
DEVELOPMENT																				
GOVT PROJECT MANPOWER																				
RETROFIT																				
DESIGN																				
CERTIFICATION FACILITY																				
CONTRACT DEPOT																				
WARRANTY																				

Figure 7-1 Life Cycle Cost Trade Table

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